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WATER POLLUTION INVESTIGATION: DULUTH-SUPERIOR AREA

A. D. McElroy, et al

Midwest Research Institute

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October 1974

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WATER POLLUTION INVESTIGATION: DULUTH-SUPERIOR AREA

U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION V ENFORCEMENT DIVISION
GREAT LAKES INITIATIVE CONTRACT PROGRAM

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OCTOBER, 1974

WATER POLLUTION INVESTIGATION:

DULUTH-SUPERIOR AREA

by

A. D. McElroy
S. Y. Chiu

MIDWEST RESEARCH INSTITUTE

In fulfillment of

EPA Contract No. 68-01-1593

for the

U.S. ENVIRONMENTAL PROTECTION AGENCY
Region V

Great Lakes Initiative Contract Program
Report Number: EPA-905/9-74-014

EPA Project Officer: Howard Zar

October 1974

This report has been developed under auspices of the Great Lakes Initiative Contract Program. The purpose of the Program is to obtain additional data regarding the present nature and trends in water quality, aquatic life, and waste loadings in areas of the Great Lakes with the worst water pollution problems. The data thus obtained is being used to assist in the development of waste discharge permits under provisions of the Federal Water Pollution Control Act Amendments of 1972 and in meeting commitments under the Great Lakes Water Quality Agreement between the U.S. and Canada for accelerated effort to abate and control water pollution in the Great Lakes.

This report has been reviewed by the Enforcement Division, Region V, Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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16. Abstracts: The Lower St. Louis River Basin from Brookston to Lake Superior was sampled in late 1973. The resultant data were combined with historical data for verification of a water quality model--the St. Louis River Basin Model, developed under a separate contract (EPA No. 68-01-1853).

The model was used to evaluate the effect on water quality of implementing effluent limits using best practicable technology and best available technology for industrial discharges, and secondary treatment for municipal waste sources, as required by the 1972 Amendments to the Federal Water Pollution Act. The study indicates that implementation of the above effluent limits, as well as utilization of a centralized treatment plant of advanced design, will result in a significant improvement in water quality in the Lower St. Louis River. However, with current benthic oxygen demand rates, DO in the reservoirs is projected to border on noncompliance at summer low flow, even with essentially zero discharge of pollutants from industrial and municipal sources in the Cloquet area.

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This report was authored by Dr. McElroy and Dr. Chiu.

Approved for:

MIDWEST RESEARCH INSTITUTE

for H. M. Hubbard, Director
Physical Sciences Division

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SUMMARY

The St. Louis River Basin, from Brookston to Lake Superior, was sampled at 18 locations in a 2-week period, in late November, and early December of 1973. Collected samples were analyzed for dissolved oxygen, pH, temperature, BOD_5, BOD_{20}, fecal coliform, total coliform, NH_3, Kjeldahl nitrogen, nitrite, nitrate, total phosphorus, available phosphorus, sulfide, sulfate, TDS, and chlorophyll A. Samples of benthic sludges were collected from four reserviors, their oxygen uptake rates were measured, and sludge bed dimensions were checked against historical data. Flows were measured at eight locations in the basin.

The resultant data were combined with historical data on hydrology, water quality, and point source discharge data for industry, municipalities, and shipping. The total data base served two functions:

1. Development and verification under a separate contract (EPA No. 68-01-1853) of a water quality model--the St. Louis River Model.

2. Development and analysis of present discharge profiles and attendant water quality; and projections of water quality which will obtain when the provisions of the 1972 Amendments to the Water Quality Act are complied with.

Two principal future discharge configurations and effluent levels were analyzed. In Treatment Configuration No. 1 the present multiple discharges are reduced to three:

1. A Western Lake Superior Sanitary District (WLSSD) centralized treatment plant of advanced design, which discharges into St. Louis Bay.

2. The Superior Municipal Treatment Plant, upgraded to secondary standards.

3. Superior Fiber Products, Inc., upgraded to 1977 effluent guidelines, discharging into Superior Bay.

Treatment Configuration No. 2 was comprised of all present discharges upgraded to conform to 1977 effluent guidlines.

Summer (570 cfs) and Winter (410 cfs, ice cover) low flow conditions were projected.

Present conditions are generally in substantial violation of stream standards. Remarkable improvement is realized with both of the above configurations. Compliance with rigid effluent guidelines is necessary if stream standards are to be achieved in the reservoirs present in the midsection of the basin. Benthic sludges limit the quality achievable in the reservoirs: water quality in this section borders on noncompliance at summer low flow, even with essentially zero discharge of pollutants upstream of the WLSSD discharge.

Calculations of present and projected water quality yield data for Superior Bay which are in error for the months during which the seiche effect promotes backflow and dispersion and mixing in the Bay. The St. Louis River Model is not presently equipped to handle this irregular, tidal-like phenomenon.

SECTION I

INTRODUCTION

The St. Louis River has its headwaters in Seven Beaver Lake in St. Louis County, approximately 163 miles above Lake Superior. It winds westward through the Missabe Iron Range and then south and east through Floodwood and Cloquet to Lake Superior. The river has a drainage area of approximately 3,430 square miles above Scanlon (see Figure 1).

The section of the river above Brookston is relatively unused for recreational or industrial purposes. The section of the river downstream from Brookston (see Figure 2), particularly from Cloquet to the Superior Lake entries, has been used for disposal of wastewater from industries, municipalities, and shipping vessels. Industrial discharges presently contribute heavy loads to the system. The major discharge is BOD, and present discharges are high in biodegradable solids which have the potential to settle in reservoirs. Municipal discharges range from the small effluents of villages to the high volume discharges of Duluth and Superior; practically all discharges in this category are primary treatment system effluents.

The downstream section of the river, from Brookston to Lake Superior, is covered in this study.

The river in this area has been intensively developed for hydro-electric power generation, with five dams in a 15-mile stretch. The pools above the dams are relatively inacessible to the public and are of limited value for use other than power development. The discharge of settleable waste materials from municipal, industrial, and natural sources for many years has resulted in extensive sludge coverage of the bottom of these pools. Oxygen uptake by sludge deposits is an important factor in the water quality of the river.

From the Thomson Reservoir, the river flow is diverted to a hydro-electric plant by a canal and three underground pipelines.

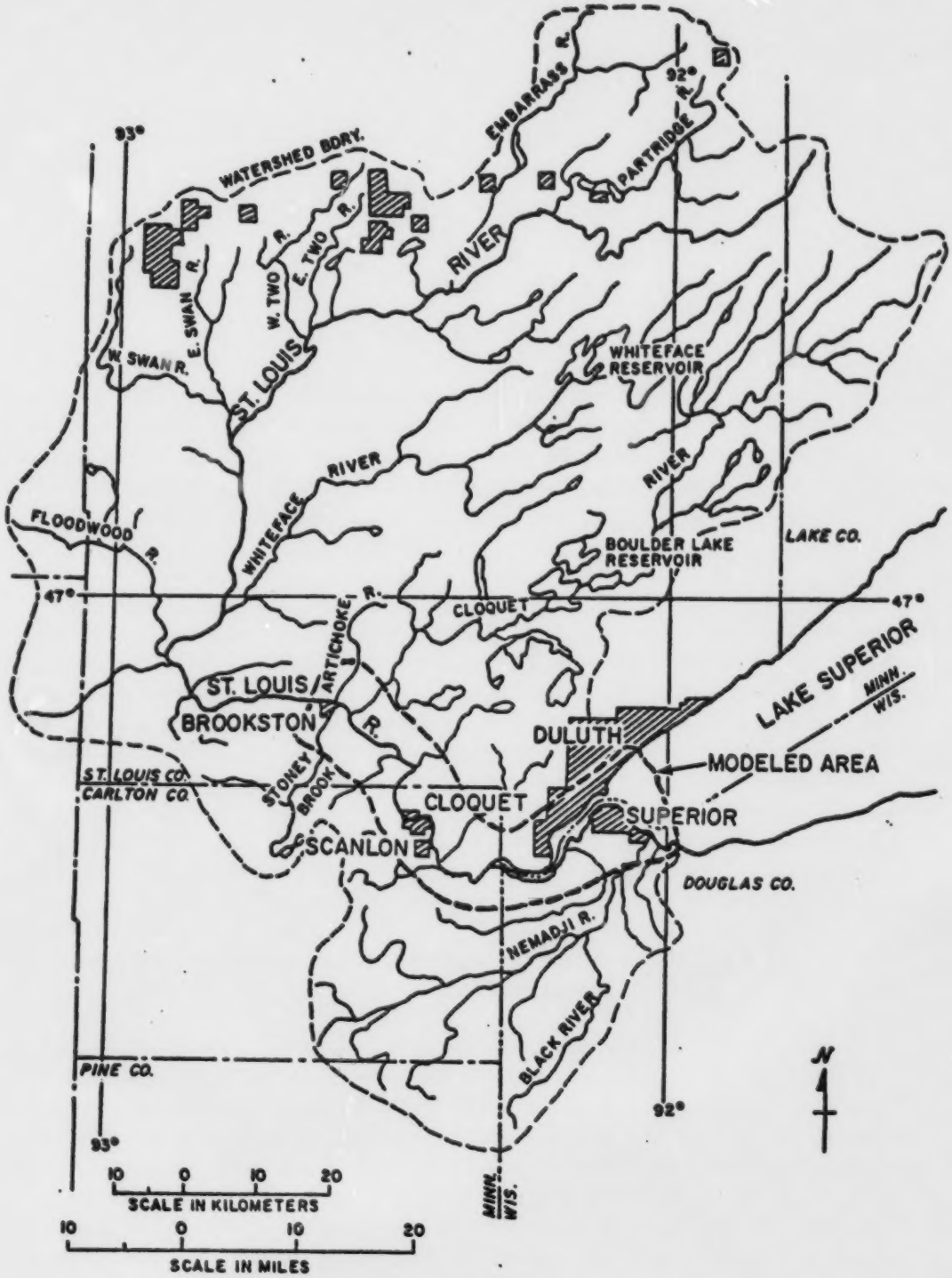


Figure 1 - The St. Louis River Basin

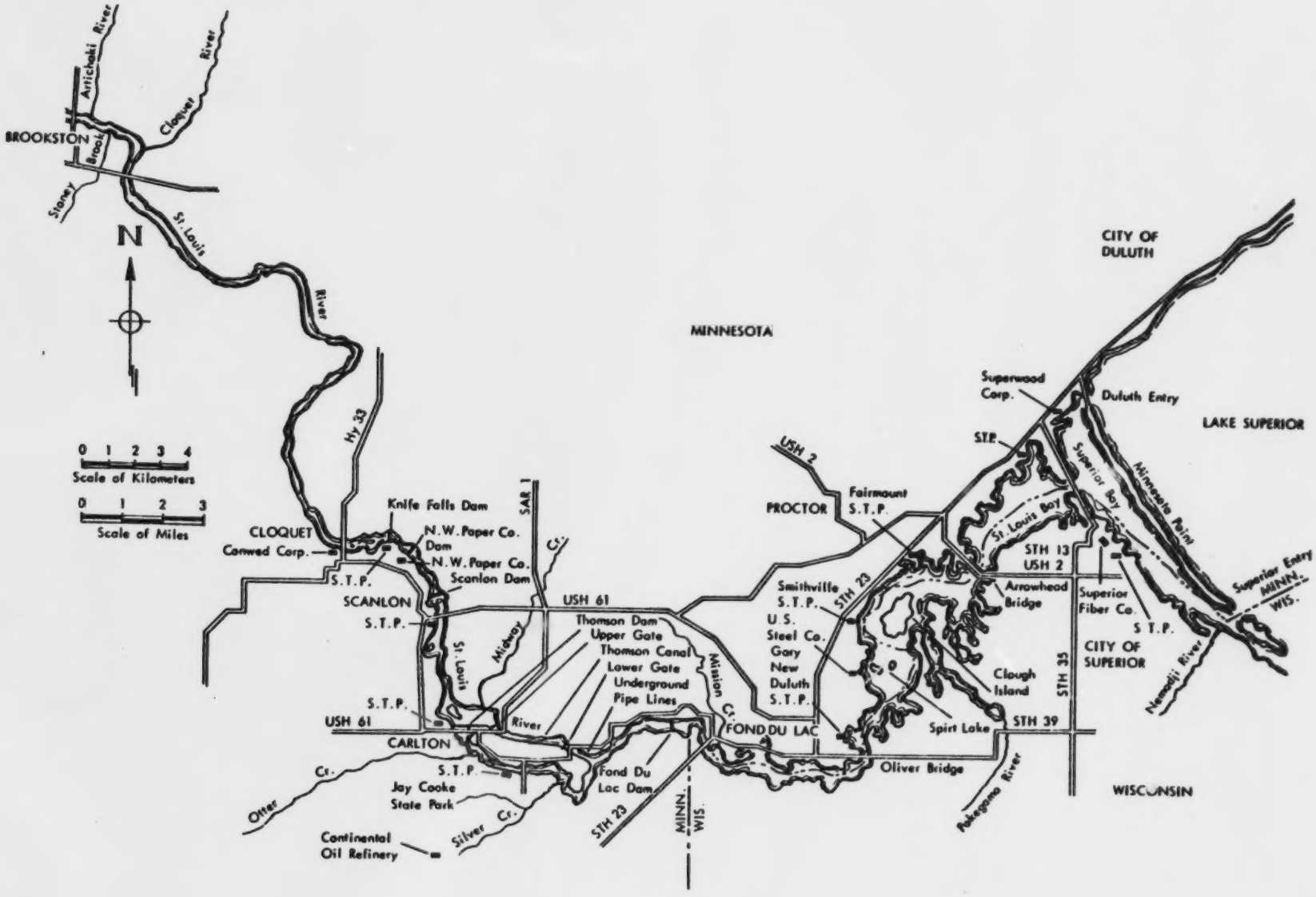


Figure 2. Overview of the Study Area

During periods of low flow, the main portion of the river flow is discharged through the diversion.

Below Fond du Lac the river widens out, with many coves, and discharges into Spirit Lake and the St. Louis Bay, which form the Inner Harbor. Connected to the St. Louis Bay are Superior Bay and the Allouez Bay, which together form the Outer Harbor. From the Outer Harbor, the St. Louis River drains into Lake Superior through the Duluth Ship Canal and the Superior Entry. This part of this river (from Fond du Lac to the Lake entries) is primarily used for harborage, dockage, and navigation by lake and ocean shipping.

The lower St. Louis River, below Cloquet, has a serious pollution problem. The pollution is indicated by reduced levels of dissolved oxygen in the summer months, excessive BOD concentrations, and high coliform counts, as illustrated by the two profiles for BOD and DO presented in Table 1. Both profiles are taken from smooth curves drawn through water quality data obtained in July/August 1973 and November/December 1973 (see Sections III and IV).

Because of the continuing gross water pollution in the river, the U. S. Environmental Protection Agency (EPA), the Minnesota Pollution Control Agency (MPCA), the Wisconsin Department of Natural Resources (WDNR), and the Western Lake Superior Sanitary District (WLSSD), have initiated a series of enforcement actions involving industrial and municipal waste dischargers in the area. In addition, the 1972 Amendments to the Federal Water Pollution Control Act (Public Law 92-500) require that municipalities shall provide, as a minimum, secondary treatment, and industries shall achieve "best practical technology" (BPT) by no later than 1977. The law also requires that industries shall use "best available technology" (BAT) to control water pollution by 1983; that publicly-owned waste treatment plants apply BPT over the life of the treatment works by 1983; and that new public waste treatment plants use the best available technology after 1983. In addition to meeting the municipal and industrial guidelines, the Amendments require that stream water quality standards must be met.

The purpose of the work presented here was to conduct an extensive survey of the river with respect to water quality and pollutant loadings, and to predict future water quality conditions by using the mathematical model which has been adapted to the river in a separate program.[1/]

Table 1. DO AND BOD PROFILES, 1973
ST. LOUIS RIVER - DULUTH ENTRY TO BROOKSTON

River kilometer[a/]	July/August 1973		November/December 1973	
	BOD	DO	BOD	DO
0	2.0	--	--	--
5	0.5	4.5	7.0	12.0
20	2.0	3.0	9.5	12.7
30	5.5	2.0	10.0	13.3
40	7.7	3.6	10.5	13.4
41	--	1.0	--	--
50	13.0	5.8	13.0	13.4
60	2.3	7.3	3.2	12.8
70	2.5	7.0	3.2	12.2
82	3.3	6.6	3.2	11.7

a/ Distance from Duluth Entry.

SECTION II

SCOPE OF THE STUDY

The scope of the study includes the following:

Task I - Historical Data Analysis: A review and documentation of data on stream water quality, point discharges, flows, and other parameters which describe river basin water quality up to September 1973. The analysis includes an evaluation of data for adequacy and completeness. A majority of Task I was completed prior to initiation of this program, under EPA Contract No. 68-01-1853. This report will therefore summarize the total data base, including data obtained in Task II, below.

Task II - Field Sampling: An intensive sampling program structured to fill in certain data gaps, generally improve the overall adequacy of the data base, and provide a set of data (for one condition) to be used in model verification. A summer low flow condition was desired, but the weather and other factors conspired to delay the sampling until late November of 1973. The sampled condition was therefore moderate flow, near freezing temperatures, generally high dissolved oxygen levels, and in-stream pollutant concentrations expected for a period of transition from a summer to a winter condition.

Task III - Effluent Analysis: Documentation of the profile of discharges to the St. Louis River, based primarily on NPDES permit data. Present discharge conditions were established for the periods when data were taken for model verification. Two possible discharge profiles for the future were documented, so that water quality could be projected for conditions established in accordance with provisions of Public Law 92-500.

Task IV - Data Analysis and Projection: Description of present water quality, projection of future water quality, and delineation of problem areas. The model developed under EPA Contract No. 68-01-1853[1/]

is the principal working tool for projections of levels of water quality that would result if effluent guidelines established by the EPA administrator under Sections 301 (b)(1)A, 301 (b)(1)B, 301 (b)(2)A, and 301(b)(2)B of the 1972 Amendments were met. If stream standards are not met by adherence to the above provisions of the law, calculations are to be made of effluent levels which will suffice to meet standards for the "protection of fish, shellfish, and wildlife, and provide for recreation in or on the water."

Results of Tasks I and II are presented in Section III--The Data Base for the St. Louis River Basin. Task III results are presented in Section IV--Effluent Analyses, and Task IV results are presented in Section V. Overall results are discussed in Section VI--Discussion, and Recommendations are presented in Section VII.

SECTION III

THE DATA BASE FOR THE ST. LOUIS RIVER BASIN

A study of the availability of data on stream water quality, stream hydrology, and discharges to the basin was conducted under EPA Contract No. 68-01-1853. This analysis is recorded in the Phase I Report for that program.[2/] Briefly, it was concluded that certain data gaps and deficiencies existed, and that these precluded satisfactory verification of the St. Louis River Model. The field sampling program (Task II) was initiated to provide further data; in particular, a set of data for the entire river basin, for a sampling period of approximately 2 weeks, was needed to serve as verification data.

In this section, the substance and quality of the data base are summarized. Presentation of specific data is for the most part deferred to Section IV-Discharge Profile Analysis, and Section V-Data Analysis and Projection.

TASK I - HISTORICAL DATA ANALYSIS

Data required for description of water quality, and of inputs to the system which impact water quality, include the following.

Hydrology Data

Flow Data - A comprehensive set of data on main stem flows, inputs from tributaries, and significant withdrawals or discharges from industries is required for each verification. A less comprehensive set of flow data for other flow regimes, especially those which are critical in water quality planning--typically summer low flow and winter low flow, was also desired.

River Dimensions - River widths and depths must be known throughout the basin, including the location and dimensions of shipping channels, reservoirs, and islands.

Stream Slopes - Changes in channel elevation, including discontinuities, must be accurately known.

The overall quantity and quality of hydrology data at the time of initiation of this program were judged to be good, with the exception that data on inputs of various tributaries to the main stem were generally inadequate.

The field sampling undertaken in Task II included measurement of stream flows at several key points. The data so obtained, in combination with basic basin data, provide a good description of the stream flow of the basin in late November - early December 1973. Additionally, the November-December data provide information needed to develop the hydraulic model for the Summer 1973 verification period.

The stream flow and river geometry data have been used to develop the hydraulic submodels of the St. Louis River Model. With these submodels, river basin hydraulics under a wide range of conditions can be accurately simulated. Brief mention should be made here of two problems, which are discussed in detail elsewhere (Reference 1, and Sections V and VI of this report).

First, the hydraulics of Superior Bay is not accurately described by the St. Louis River Model. Inaccuracies are due to mixing/dispersion in the Bay caused by the seiche (tidal) effect, and calculated water quality is thus inferior to actual (but previously not documented) water quality in the Bay. Rectification of this defect will require further data gathering followed by modification of the model.

Second, the stream bed slopes relatively steeply in its mid-section, and somewhat artificially low friction coefficient values were used to permit achievement of steady state hydraulics.[1/] This solution of the problem is mentioned chiefly for the benefit of those who would attempt to improve the model or to adapt the model to other river systems.

Stream Water Quality Data - Model verification requires historical data on several water quality and water property parameters at multiple locations in the basin, and preferrably at two or more significantly different conditions. Complete sets of data for a summer flow condition and for a winter flow condition will suffice, for example. In addition, broad coverage of water quality throughout the basin is useful as a check on general validity of the model. Parameters needed for the St. Louis River are temperature, pH, DO, BOD, P, N, NO_2, NO_3, NH_3, S, $SO_4^=$, total coliform, fecal coliform, algae, chlorophyll A, and TDS.

In addition, oxygen uptake rates and bed dimensions for benthic sludges are required where such deposits are significant.

With the exception of a few parameters, coverage of the above listed parameters through the summer of 1973 was fairly extensive, and Summer 1973 data were judged to be nearly adequate for model verification at one condition. A data set for another condition was needed to facilitate model verification, however, and data on certain of the parameters listed above were nonexistent (see Reference 2, Data Report on EPA Contract No. 68-01-1853). The sampling program (Task II) was designed to remedy key data deficiencies, and generate data for a second verification condition.

Discharge Data - The volumes and composition of municipal and industrial discharges must be known, particularly during selected verification periods. General historical data will suffice if the discharges are relatively constant as is usually the case.

Data on municipal discharges are adequate, though by no means complete with respect to the parameters listed above. Industrial discharge data, derived chiefly from information in the NPDES Program, were somewhat scanty but proved to be generally adequate for model verification and projections of water quality.

Shipping is an important activity in the Bay areas, and data on shipping wastes are necessary. No data were found on actual discharge volumes and compositions. Information on ship movements was combined with literature documentation of shipping wastes, and loads thereby calculated. (Shipping wastes proved to be of minor importance, and error in the above procedure will have virtually no impact on calculated water quality parameters.)

TASK II - FIELD SAMPLING

Sampling was initiated on 19 November 1973, and completed on 5 December 1973. Additional samples were taken during the following week by personnel of Western Lake Superior Sanitary District. Temperatures were near freezing during the sampling period, and ice skims began to form on parts of the system in early December. Dissolved oxygen concentrations were uniformly high, as expected, and photosynthetic processes were essentially at a standstill. Relatively heavy rainfall had occurred earlier in the fall, and the river flow, at 2,400 cfs, was substantially higher than either a winter or summer low flow condition.

Five locations--Highway 33 Bridge at Cloquet, Scanlon Dam, Forbey Lake--Lower Gate, Fond du Lac Bridge, and Oliver Bridge--were sampled four times daily on 27, 28, and 29 November. Temperature, DO and pH were measured as samples were taken. Fourteen parameters were measured in the laboratory; these were BOD_5, BOD_{20}, fecal coliform, total coliform, NH_3, Kjeldahl nitrogen, nitrate, nitrite, total phosphorus, available phosphorus, sulfide, sulfate, TDS, and chlorophyll A. Data for these samples are reported in Tables 2 through 6. These five stations were resampled once per day on 8 and 9 December, and samples were analyzed for DO, BOD_5, and BOD_{20} (Table 7).

Thirteen stations listed in Table 8 were sampled once per day on 30 November, 3 December, and 4 December. These samples were analyzed for the parameters listed above.

Bottom sludge samples were recovered from Knife Falls Dam, Scanlon Dam, Thomson Lake, and Northwest Paper Company Dam. uptake take rates, moisture, and volatile solids were measured for 12 sludge samples; data are presented in Tables 9 and 10.

Flow data were measured at eight locations. The data are summarized in Table 11.

Table 2. INTENSIVE SAMPLING, HIGHWAY 33 BRIDGE AT CLOQUET

Date/Time	D.O.	pH	Temperature °C	BOD_5	BOD_{20}	Fecal Coliform MPN/100 ml	Total Coliform MPN/100 ml	NH_3 mg/l	Total Kjeldahl Nitrogen mg/l	Nitrate mg/l	Nitrite mg/l	Total Phosphorus mg/l	Available Phosphorus mg/l	Sulfide mcg/l	Sulfate mg/l	TDS mg/l	Chlorophyll mg/l
11-27-73 08:30	13.3	8.0	1.0			83	2,200	0.11	1.0	0.42	0.01	0.10	0.10	<10	9.5	93	<0.01
12:40	17.5	7.7	1.0			55	3,240	0.21	1.0	0.41	<0.01	0.15	0.13	<10	8.0	132	<0.01
16:30	12.8	6.9	1.2							0.37	<0.01						<0.01
20:10	15.5	7.7	0.8							0.36	<0.01						<0.01
11-28-73 08:55	15.4	8.0	0.0			46	720	0.529	0.301	0.308	0.004	0.441	0.378	<50	9.60	0	<0.01
12:50	16.1	7.3	0.0			12	9,300	0.072	0.235	0.201	0.003	0.124	0.049	<50	8.00	25	<0.01
16:50	11.6	7.2	0.9							0.307							<0.01
20:30	14.0	7.7	0.3							0.332							<0.01
11-29-73 09:15	14.7	7.3	0.0	3.8	30	80	1,800	0.11	1.0	0.36	<0.01	0.10	0.07	<10	8.0	52	<0.01
13:00	14.0	7.4	1.0	3.4	30.3	48	1,600	0.043	0.214	0.175	0.002	0.074	0.047	<50	10.75	135	<0.01
16:50	15.1	7.2	1.0	2.8						0.10	0.01						<0.01
19:20	14.0	7.4	1.0	3.9						0.320							<0.01

Table 3. INTENSIVE SAMPLING, SCAMLON DAM

Date/Time	D.O.	pH	Temperature °C	BOD_5	BOD_{20}	Fecal Coliform	Total Coliform	NH_3 mg/l	Total Kjeldahl Nitrogen mg/l	Nitrate mg/l	Nitrite mg/l	Total Phosphorus mg/l	Available Phosphorus mg/l	Sulfide mg/l	Sulfate mg/l	TDS mg/l	Chlorophyll mg/l
11-27-73 09:10	11.9	7.8	2.0			a/	13,300	0.21	1.0	0.39	0.02	0.15	0.10	<10	15.0	159	<0.01
13:10	14.3	7.7	2.0			a/	17,600	0.16	1.0	0.43	0.01	0.15	0.12	<10	16.5	160	<0.01
17:00	14.6	7.0	1.0							0.39	<0.01						<0.01
20:35	16.0	6.9	1.0							0.42	0.03						<0.01
11-28-73 09:15	14.7	7.5	0.0			69	9,300	0.200	0.284	0.248	0.004	0.141	0.049	<50	14.25	168	<0.01
13:10	16.1	7.2	0.0			22	7,100	0.114	0.389	0.281	0.003	0.119	0.049	<50	15.50	234	<0.01
17:10	11.4	7.3	0.3							0.332							<0.01
20:10	13.6	7.6	0.7							0.328							<0.01
11-29-73 09:30	14.0	7.2	0.0	8.4	>49	80	10,400	0.19	1.6	0.22	<0.01	0.12	0.01	<10	18.75	34	<0.01
13:15	13.3	7.3	1.0	15.4	>48	80	11,700	0.029	0.256	0.206	0.003	0.122	0.057	<50	18.75	102	<0.01
16:50	14.6	7.3	1.1	15.2						0.35	0.01						<0.01
19:40	13.8	7.3	1.0	13.6						0.339							0.03

a/ Plates overgrown with too colonies.

Table 4. INTENSIVE SAMPLING, FORBEY LAKE-LOWER GATE

Date/Time	D.O.	pH	Temperature °C	BOD_5	BOD_{20}	Fecal Coliform	Total Coliform	NH_3 mg/l	Total Kjeldahl Nitrogen mg/l	Nitrate mg/l	Nitrite mg/l	Total Phosphorus mg/l	Available Phosphorus mg/l	Sulfide mcg/l	Sulfate mg/l	TDS mg/l	Chlorophyll mg/l
11-27-73 10:40	12.9	7.7	1.0			14	9,700	0.12	1.5	0.34	0.03	0.10	0.10	<10	15.8	165	<0.01
13:50	14.7	7.5	1.0			20	9,500	0.18	1.0	0.42	<0.01	0.15	0.09	<10	16.5	55	<0.01
17:30	15.0	7.0	1.0							0.18	0.05						0.10
21:00	12.6	7.0	1.0							0.34	0.01						<0.01
11-28-73 09:45	16.9	7.5	0.0			140	8,000	0.029	0.238	0.166		0.110	0.039	<50	14.50	23	<0.01
13:35	17.6	7.3	0.0			29	3,900	0.057	0.364	0.173	0.003	0.095	0.044	<50	15.85	34	<0.01
17:30	13.8	7.3	1.0							0.313							<0.01
19:45	13.8	7.5	0.5							0.311							0.01
11-29-73 10:00	13.2	7.0	0.0	6.6	44	430	11,800	0.11	1.2	0.39	<0.01	0.13	0.04	<10	14.5	99	<0.01
13:30	13.3	7.3	1.0	10.9	43	170	7,100	<0.015	0.459	0.171	0.003	0.115	0.034	<50	16.00	172	<0.01
17:30	13.2	7.4	2.8	13.0						0.35	0.02						0.10
20:05	13.2	7.3	1.0	11.6						0.305							<0.01

Table 5. INTENSIVE SAMPLING, POND DU LAC BRIDGE

Date/Time	D.O.	pH	Temperature °C	BOD_5	BOD_{20}	Fecal Coliform	Total Coliform	NH_3 mg/ℓ	Total Kjeldahl Nitrogen mg/ℓ	Nitrate mg/ℓ	Nitrite mg/ℓ	Total Phosphorus mg/ℓ	Available Phosphorus mg/ℓ	Sulfide mcg/ℓ	Sulfate mg/ℓ	TDS mg/ℓ	Chlorophyll mg/ℓ
11-27-73 09:10	13.4	7.6	1.0			118	4,700	0.11	1.4	0.32	0.03	0.10	0.07	<10[a/]	14.5	121	<0.01
13:30	13.5	7.5	1.0			39[a/]	7,900	0.11	1.2	0.30	<0.01	0.10	0.09	<10[a/]	16.5	183	<0.01
17:16	13.6	7.6	1.0							0.39	<0.01						<0.01
20:36	13.5	7.5	1.0							0.36	0.02						<0.01
11-28-73 09:28	13.7	7.7	1.0			116	4,300	0.057	0.266	0.177	0.006	0.110	0.031	<50	18.75	46	<0.01
13:25	13.8	7.4	1.0			85	3,900	<0.015	0.343	0.180	0.004	0.107	0.039	<50	13.50	109	<0.01
17:05	14.0	7.4	1.0							0.286							<0.01
20:05	14.0	7.2	0.8							0.309							<0.01
11-29-73 09:35	13.9	7.2	0.0		46	270	6,700	0.11	1.4	0.39	<0.01	0.12	0.07	<10	16.5	111	<0.01
13:30	13.8	7.4	1.0	10.4		160	7,000	0.072	0.270	0.303	0.003	0.091	0.034	<50	16.25	53	<0.01
17:10	13.8	7.3	1.2	10.2						0.36	<0.01						<0.01
19:50	14.0	7.3	1.0	11.5						0.290							<0.01

a/ Overgrown with tan colonies.

Table 6. INTENSIVE SAMPLING, OLIVER BRIDGE

Date/Time	D.O.	pH	Temperature °C	BOD_5	BOD_{20}	Fecal Coliform	Total Coliform	NH_3 mg/ℓ	Total Kjeldahl Nitrogen mg/ℓ	Nitrate mg/ℓ	Nitrite mg/ℓ	Total Phosphorus mg/ℓ	Available Phosphorus mg/ℓ	Sulfide mcg/ℓ	Sulfate mg/ℓ	TDS mg/ℓ	Chlorophyll mg/ℓ
11-27-73 08:40	12.5	7.5	1.0			117	4,100	0.11	1.0	0.36	<0.01	0.10	0.09	<10	13.3	133	<0.01
12:55	12.9	7.6	1.0					0.11	1.1	0.29	<0.01	0.10	0.07	<10	15.8	126	<0.01
16:50	13.0	7.8	1.0							0.29	<0.01						<0.01
21:05	12.0	7.5	1.0							0.31	<0.01						<0.01
11-28-73 08:55	12.8	7.6	0.0			104	5,800	<0.015	0.364	0.300	0.003	0.107	0.028	<50	17.15	73	<0.01
13:05	13.1	7.4	0.0			93	3,400	<0.15	0.280	0.288	0.004	0.105	0.026	<50	19.65	82	<0.01
16:35	13.2	7.4	1.0							0.286							<0.01
20:25	13.1	7.5	0.6							0.290							<0.01
11-29-73 09:15	13.4	7.3	0.0	6.0	>50 44	90	6,600	0.11	1.2	0.37	0.02	0.12	0.07	<10	20.0	128	<0.01
13:10	13.3	7.3	1.0	10.5	40	250	7,500	0.029	0.466	0.313	0.004	0.124	0.026	<50	18.00	56	<0.01
16:50	13.6	7.4	1.5	9.9						0.35	<0.01						<0.01
20:15	13.2	7.2	1.0	11.2						0.309							<0.01

Table 7. ONCE-A-DAY SAMPLING POINTS - ST. LOUIS RIVER
ADDITIONAL SAMPLES TAKEN BY WLSSD
TEMPERATURE: 0°C

Sampling Point	Date/Time	D.O.	BOD_5	BOD_{20}
Bridge at Cloquet Highway 33	12-8-73 09:00	13.3	2.8	7.5
Bridge at Cloquet Highway 33	12-9-73 09:00		3.9	13.5
Scanlon Dam	12-8-73 10:00	13.5	13.9	30
Scanlon Dam	12-9-73 10:00		17.0	30
Lower Gate	12-8-73 11:00	12.8	12.2	75
Lower Gate	12-9-73 11:00		14.6	29
Fond du Lac Bridge	12-8-73 12:00	13.8	15.0	31
Fond du Lac Bridge	12-9-73 12:00		15.1	32
Oliver Bridge	12-8-73 13:00		11.3	33.2
Oliver Bridge	12-9-73 13:00		14.7	29

Table 8. ONCE-A-DAY SAMPLING POINTS - ST. LOUIS RIVER

Sampling Point	Date/Time	D.O.	pH	Temperature °C	BOD_5	BOD_{20}	Fecal Coliform	Total Coliform	NH_3 mg/ℓ	Total Kjeldahl Nitrogen mg/ℓ	Nitrate mg/ℓ	Nitrite mg/ℓ	Total Phosphorus mg/ℓ	Available Phosphorus mg/ℓ	Sulfide mcg/ℓ	Sulfate mg/ℓ	TDS mg/ℓ	Chlorophyll mg/ℓ
Cloquet River Bridge at Burnett	11-30-73 10:55	13.9	7.5	0.0	3.4	19.0	5	200	<0.015	0.301	0.189	0.001	0.074	0.039	<50	1.0	194	<0.01
	12-3-73 15:00	12.3	7.1	0.0	2.0	7.0	4	940	0.11	1.5	0.07	0.05	<0.05	0.04	<10	<0.5	88	
	12-4-73 12:00	11.5	7.1	0.0	3.1	8.0	2	640	0.022	0.333	0.222	0.003	0.038	0.121	<50	1.0	88	
Brookston Bridge St. Louis River	11-30-73 11:15	13.2	7.4	0.0	4.1	17.5	10	200	0.072	0.305	0.398	0.003	0.134	0.057	<50	19.85	17	0.02
	12-3-73 14:15	11.2	7.2	1.0	3.0	6.5	96	1,690	0.19	1.0	0.19	0.05	0.10	0.08	<10	12.0	157	
	12-4-73 12:30	10.7	7.0	0.0	2.7	8.5	108	700	0.464	0.291	0.374	0.003	0.086	0.050	<50	15.00	149	
Scanlon Bridge I-35 St. Louis River	11-30-73 10:15	13.3	7.4	0.0	13.8	29.0	130	3,900	0.22	0.6	0.35	<0.01	<0.05	0.04	<10	5.0	65	0.04
	12-3-73 11:35	10.5	7.4	1.0	9.4	24.0	90	3,900	0.20	1.0	0.14	0.05	0.10	0.08	<10	10.0	168	
	12-4-73 09:50	10.7	6.7	0.0	12.7	22.0	550	5,400	0.135	0.221	0.294	0.002	0.064	0.033	<50	14.50	208	
Crystal Creek at Carlton	11-30-73 12:00	13.3	7.3	1.0	16.7	26.5	3,000	110,000	0.172	1.125	0.851	0.013	0.659	0.481	<50	22.50	281	0.13
	12-3-73 11:55	8.6	7.4	3.0	11.0	34.5	16,100	648,000	0.91	3.0	0.71	0.21	0.55	0.40	<10	15.8	112	
	12-4-73 10:10	10.7	6.7	0.0	4.6	20.5	16,400	104,000	0.090	0.582	0.915	0.008	0.189	0.113	<50	21.00	177	
Silver Creek	11-30-73 11:10	14.0	7.5	0.0	3.9	20.3	<10	100	<0.015	0.091	1.010	0.008	0.284	0.241	<50	64.60	231	0.04
	12-3-73 11:45		7.9		2.0	12.0	2[a]	320	0.22	<0.5	0.94	0.11	0.30	0.28	<10	18.5	313	
	12-4-73 10:05		8.0		1.3	15.0	4	1,340	0.360	0.105	0.986	0.009	0.286	0.258	<50	66.0	323	

Table 8. (CONCLUDED)

Sampling Point	Date/Time	D.O.	pH	Temperature °C	BOD_5	BOD_{20}	Fecal Coliform	Total Coliform	NH_3 mg/ℓ	Total Kjeldahl Nitrogen mg/ℓ	Nitrate mg/ℓ	Nitrite mg/ℓ	Total Phosphorus mg/ℓ	Available Phosphorus mg/ℓ	Sulfide mcg/ℓ	Sulfate mg/ℓ	TDS mg/ℓ	Chlorophyll mg/ℓ
Spirit Lake	11-30-73 Not Taken																	
	12-3-73 11:20	11.6	7.2	1.0	9.4	27	76	660	0.95	3.0	0.08	0.10	0.15	0.15	<10	6.5	160	
Pokegma	11-30-73 Not Taken																	
	11-30-73 11:20	11.2	7.0	0.0	3.8	18	<10	100	0.18	1.2	0.41	0.03	0.20	0.20	<0.01	18.5	166	0.08
	12-3-73 11:40	15.8	7.3	0.0	2.6	7.0	22	100	0.13	1.2	0.28	0.01	0.14	0.12	<10	7.5	213	
	12-4-73 10:00	15.4	7.4	01.2	1.6	8.0	34	2,370	0.637	0.407	0.450	0.003	0.169	0.139	<50	17.75	202	
Nemadji	11-30-73 10:00	11.2	7.0	0.0	4.0	19.5	<10	<100	0.18	1.0	0.19	0.03	0.15	0.13	<10	19.5	165	0.04
	12-3-73 14:10	14.8	7.2	0.0	2.8	6.0	8	170	0.11	0.5	0.13	<0.01	0.17	0.14	<10	8.0	145	
	12-4-73 10:55	9.4	7.3	-1.5	1.8	5.8	26	1,460	0.167	0.606	0.243	0.004	0.175	0.005	<50	11.80	140	
Superior Entry	11-30-73 10:25	9.8	6.9	1.0	2.9	22	10	200	0.16	0.9	0.36	<0.01	0.10	0.10	<10	10.0	62	0.04
	12-3-73 14:40	12.4	7.5	0.0	5.0	12	36	140	0.29	2.0	0.07	0.10	0.10	0.08	<10	15.0	147	
	12-4-73 10:50	14.6	7.2	1.0	2.3	8	46	1,030	0.345	0.231	0.350	0.003	0.150	0.030	<50	7.75	92	
Superior Treatment Plant	11-30-73 10:20	15.5	7.1	1.1	17.7	28	60	2,300	<0.015	0.634	0.296	0.005	0.146	0.057	<50	17.00	233	0.02
	12-3-73 14:30	13.6	7.4	1.3	6.2	15	32	400	0.30	1.5	0.07	0.12	0.11	0.08	<10	11.5	166	
	12-4-73 Sample Taken																	
Arrowhead	11-30-73 09:25	10.1	7.0	-1.0	6.8	28	<10	300	0.21	1.5	0.29	0.01	0.10	0.07	<10	15.0	98	0.08
	12-3-73 12:40	13.6	7.3	0.2	8.2	16	58	890	0.32	2.0	0.08	0.12	0.10	0.007	<10	12.5	160	
	12-4-73 15:50	12.4	7.1	3.3	7.1	14.5	8	2,010	0.112	0.431	0.339	0.004	0.122	0.020	<50	17.00	161	
High Bridge	11-30-73 09:40	13.0	7.1	1.1	8.7	24	580	2,100	0.186	0.442	0.359	0.002	0.277	0.057	<50	16.80	44	<0.01
	12-3-73 12:20	12.9	7.3	1.0	6.0	12	20	100	0.23	1.5	0.23	0.10	0.15	0.13	<10	12.0	154	
Duluth Entry	12-4-73 11:50	12.5	7.0	1.0	6.6	18.5	84	860	0.079	0.543	0.319	0.005	0.124	0.043	<50	17.75	122	
	11-30-73 09:00	10.2	7.0	2.5	4.7	22	<10	200	0.17	1.2	0.35	<0.01	0.10	<0.10	<10	8.0	46	0.02
	12-3-73 15:20	13.8	7.4	1.5	1.8	4.5	50	650	0.11	0.5	0.20	0.05	0.07	0.06	<10	4.5	77	
	12-4-73 12:55	13.8	7.3	3.0	0.9		140	1,130	0.142	0.137	0.322	0.003	0.043	0.015	<50	5.20	129	

a/ Excessive grey colonies.

Table 9. OXYGEN UPTAKE OF LAKE SLUDGES IN ST. LOUIS RIVER SYSTEM (MEASUREMENTS AT ROOM TEMPERATURE, 25°C)

Sample Description	Sample No.	Moisture (%)	Volatile Solids (%)	Oxygen Uptake ($g/m^2/day$)
Knife Fall Dam,	1	46.4	6.8	5.7
taken 1200 hr	2	47.5	6.6	6.4
11-19-73, 20 ft	3	--	--	6.1
off north wall,	4	--	--	7.0
34°F, fingernail	5	49.5	7.3	4.3
clams present	6	45.0	7.0	4.0
Average		47.1	6.9	5.6
Knife Fall Dam,	7	--	--	3.2
taken 1230 hr	8	37.5	5.2	4.2
11-19-73, 100 yd	9	52.2	10.1	4.6
downstream	10	60.5	14.4	3.1
from sewage	11	56.1	9.1	5.2
effluent, 8 ft offshore by 3 telephone poles, 34°F	12	55.2	10.2	4.9
Average		52.3	9.8	4.2
Scanlon Dam, taken	13	53.1	9.2	6.7
1520 hr 11-19-73	14	44.1	4.4	5.5
300 ft from dam	15	60.1	10.8	6.8
35°F	16	62.1	17.1	5.3
	17	--	--	5.6
	18	--	--	5.4
Average		54.8	10.4	5.9

Table 9. (CONTINUED)

Sample Description	Sample No.	Moisture (%)	Volatile Solids (%)	Oxygen Uptake ($g/m^2/day$)
Scanlon Dam, taken	19	65.7	17.1	4.9
1532 hr 11-19-73,	20	--	--	5.5
1 ft sludge depth,	21	62.0	15.9	5.8
300 ft from dam,	22	69.7	19.0	8.1
36°F	23	63.1	16.4	5.1
	24	63.6	16.1	5.7
Average		64.8	16.9	5.8
Thomson Lake, taken	25	51.1	8.7	5.0
1038 hr 11-20-73,	26	--	--	6.0
300 yd upstream from	27	52.0	8.6	2.9
upper gate, 35°F,	28	--	--	6.8
stratified oxidized	29	55.0	9.0	4.6
layer on top,	30	47.1	4.2	4.7
brown/black on bottom, bloodworms present, 2 ft sludge depth				
Average		51.3	7.6	5.0
Thomson Lake, taken	31	51.6	8.2	3.6
1050 hr 11-20-73,	32	--	--	4.1
600 yd from upper	33	56.8	11.9	5.3
gate, less than	34	55.9	9.5	7.1
500 yd north of	35	--	--	4.0
main dam, 35°F,	36	55.8	9.1	4.0
brown oxidized layer on top, bloodworms present				
Average		55.0	9.7	4.7

Table 9. (CONTINUED)

Sample Description	Sample No.	Moisture (%)	Volatile Solids (%)	Oxygen Uptake ($g/m^2/day$)
Thomson Lake, taken	37	--	--	5.4
1059 hr 11-20-73	38	36.3	4.6	5.9
20 yd from island	39	37.1	4.6	3.0
north of main dam,	40	--	--	3.4
middle of island	41	38.7	5.1	4.8
150 yd from north	42	40.2	5.6	3.6
shore, sludge	43	--	--	4.8
depth 22 in,	44	38.2	4.9	4.3
35°F				
Average		38.1	5.0	4.4
Thomson Lake, taken	45	42.4	5.2	7.5
1114 hr 11-20-73,	46	41.1	4.9	4.3
50-60 yd from north	47	36.6	3.5	5.1
shore opposite rock	48	--	--	1.4
pile in lake, 300	49	40.2	2.7	8.3
yd from main dam,	50	--	--	4.3
30-32 in. sludge depth, 35°F, blood-worms present				
Average		40.1	4.1	5.2
Thomson Lake, taken	51	--	--	3.2
1130 hr 11-20-73, 30	52	25.6	1.0	1.2
yd off large island,	53	--	--	1.5
40 yd from north	54	30.0	2.1	1.5
shore, 22 in. sludge	55	26.6	1.2	1.4
depth, sand mixed	56	25.5	1.0	1.0
with sludge, 35°F	57	--	--	0.3
	58	37.7	3.0	0.7
Average		29.1	1.7	1.4

Table 9. (CONCLUDED)

Sample Description	Sample No.	Moisture (%)	Volatile Solids (%)	Oxygen Uptake ($g/m^2/day$)
Thomson Lake, taken 1150 hr 11-20-73, Carlton side of lake, 150 yd from treatment plant, 20 yd south end of island, 30 in. sludge depth, 35°F	59	42.3	4.4	4.9
	60	--	--	4.8
	61	58.0	10.4	4.9
	62	--	--	5.9
	63	57.6	10.9	5.2
	64	57.0	9.8	3.7
Average		53.7	8.9	4.9
Northwest Paper Dam, taken 1450 hr 11-20-73, 20 ft from shore opposite plant, 200 yd from dam	65	50.1	7.0	5.0
	66	50.1	6.9	2.6
	67	49.2	6.7	5.5
	68	--	--	5.1
	69	--	--	5.1
	70	47.5	6.1	5.3
Average		49.2	6.7	4.8
Northwest Paper Dam, taken 1500 hr 11-20-73, 30 ft offshore in bay opposite end of plant, about 50 yd upstream from point where samples 65-70 were taken, 18 in. sludge depth	71	--	--	7.0
	72	43.3	4.1	6.2
	73	43.4	4.3	8.0
	74	42.2	4.3	6.7
	75	--	--	6.1
	76	43.1	4.8	6.6
Average		43.0	4.6	6.8

Table 10. OXYGEN UPTAKE OF LAKE SLUDGES IN ST. LOUIS RIVER SYSTEM COMPARISON OF RATES AT 25°C AND 3°C

Sample Location	Sample No. (see Table IX)	Oxygen Uptake at 25°C (g/m^2 day)	Oxygen Uptake at 3°C (g/m^2/day)
Knife Falls Dam	2	6.4	0.3
Scanlon Dam	15	6.8	0.4
Thomson Lake	45	7.5	1.4
Northwest Paper Dam	73	8.0	0.3

Table 11. STREAM FLOW DATA ST. LOUIS RIVER/DULUTH-SUPERIOR AREA EARLY DECEMBER 1973

Sampling Point	Date	Distance From Right Bank (ft)	Depth (ft)	Width (ft)	Velocity	Flow
Brookston Bridge	12-5-73	25	4.5	275	1.4 ft/sec	3,000 ft^3/sec
		50	6			
		75	7.5			
		100	8.5			
		125	8.5			
		150	9			
		175	10			
		200	9			
		225	8			
		250	6			
Cloquet River	12-5-73	10	1.5	170	1.79 ft/sec	1,330 ft^3/sec
		20	2.5			
		40	2.0			
		60	3.5			
		80	3.5			
		100	4.0			
		120	5.0			
		140	5.0			
		160	2.0			
St. Louis River at Cloquet Bridge	12-5-73					Heavy ice, could not measure flow.
Crystal Creek	12-5-73				12 ft^3/sec estimated	
Silver Creek	12-5-73				12 ft^3/sec estimated	
Pokegma River	12-5-73		6.2	58.5		No measurable flow.
Nemadji River	12-4-73		12.4 maximum (arc shaped bottom)	187	0.46 ft/sec	820 ft^3/sec
High Bridge entry to Superior Bay		--	--		--	Measured surface flow (33 min from railway bridge to High Bridge). Corps of Engineer Data on depth and width. Calculated flow 13,500 ft^3/sec.

SECTION IV

EFFLUENT ANALYSES

Data on municipal and industrial discharges were collected. Shipping wastes were calculated from information on the volume of ship movements in the Bay areas and accepted data on the composition and volumes of different types of shipping wastes.

The accumulated data are presented in this section.

MUNICIPAL DISCHARGES

There are eight major municipal discharges along the St. Louis River main stem. Their code letter numbers used in this study, locations in terms of latitude and longitude, as well as their distances from the reference point--which was selected as the Duluth entry--are presented in Table 12.

A report published by the Western Lake Superior Sanitary District entitled "Water Quality Management Plan: Inventory of Existing Waste Sources,"[3] has a description of the quality and quantity characteristics of these municipal discharges. In addition to the WLSSD report, we also obtained data reports from each municipal discharge.

The discharge data from these sources were evaluated and compared and summarized in Tables 13 through 19.

Some pollutant parameters were never reported. Representative data obtained from the literature were assumed for the municipal discharges in the area. Data of this category are presented in parentheses.

Table 12. MUNICIPAL DISCHARGES

No.	Name	Location Latitude/ Longitude			Distance[a] Km (mile)
M-1	Cloquet Treatment Plant	46	43	33	50.57 (31.43)
		92	26	59	
M-2	Village of Scanlon	46	42	04	45.53 (28.30)
		92	25	16	
M-3	Jay Cooke State Park	46	39	13	37.50 (23.00)
		92	22	17	
M-4	Gary-New Duluth Treatment Plant	46	39	41	21.25 (13.21)
		92	12	59	
M-5	Smithville Treatment Plant	46	42	02	14.40 (8.95)
		92	12	24	
M-6	Fairmont Treatment Plant	46	43	13	11.52 (7.16)
		92	07	52	
M-7	Duluth Main Treatment Plant	46	45	28	5.31 (3.30)
		92	07	52	
M-8	City of Superior	46	43	42	4.97 (3.09)[b]
		92	04	16	

a/ Unless otherwise indicated, the distance is measured upstream from the Duluth entry.

b/ Measured from the Superior entry.

Table 13. DISCHARGE DATA OF THE CLOQUET SEWAGE TREATMENT PLANT (PRIMARY)--M-1 (RIVER KILOMETER POINT = 50.57)

Parameters	Concentration (mg/ℓ)	Load (lb/day)	Load (kg/day)
BOD	100	1,243	563
Kjeldahl nitrogen	22.5	279	126
Ammonia nitrogen	(28)	(348)	(157)
Phosphorus	9.0	112	50
Total coliforms	31 mpn/100 ml	--	--
Total dissolved solids	(320)	(3,979)	(1,802)
Total nitrogen	(52.5)	(652)	(296)
Suspended solids	76	945	428

Flow = 0.0652 Cubic meters/sec
1.4886 Million gallons/day

Table 14. DISCHARGE DATA OF THE SCANLON SEWAGE TREATMENT PLANT (PRIMARY)--M-2 (RIVER KILOMETER POINT = 45.53)

Parameters	Concentration (mg/ℓ)	Load (lb/day)	Load (kg/day)
BOD	125	82	37
Kjeldahl nitrogen	(20)	(22)	(10)
Ammonia nitrogen	(28)	(30)	(14)
Phosphorus	92	10	(5)
Total coliforms	(2,000 mpn/100ml)	--	--
Total dissolved solids	(320)	(348)	(157)
Total nitrogen	(50)	(54)	(25)
Suspended solids	80	87	39

Flow = 0.0057 Cubic meters/sec
0.13 Million gallons/day

Table 15. DISCHARGE DATA OF THE GARY-NEW DULUTH TREATMENT PLANT (PRIMARY)--M-4 (RIVER KILOMETER POINT = 21.25)

Parameters	Concentration (mg/ℓ)	Load (lb/day)	Load (kg/day)
BOD	50	88	39
Kjeldahl nitrogen	(20)	(35)	(15)
Ammonia nitrogen	(28)	(49)	(22)
Phosphorus	(10)	(18)	(8)
Total coliforms	500 mpn/100 ml	--	--
Total dissolved solids	296	519	235
Total nitrogen	(50)	(87)	(40)
Suspended solids	34	59	27

Flow = 0.0092 Cubic meters/sec
0.21 Million gallons/day

Table 16. DISCHARGE DATA OF THE SMITHVILLE TREATMENT PLANT (PRIMARY)--M-5 (RIVER KILOMETER POINT = 14.40)

Parameters	Concentration (mg/ℓ)	Load (lb/day)	Load (kg/day)
BOD	50	133	60
Kjeldahl nitrogen	(20)	(53)	(24)
Ammonia nitrogen	(28)	(74)	(34)
Phosphorus	(10)	(27)	(12)
Total coliforms	919 mpn/100ml	--	--
Total dissolved solids	296	790	357
Total nitrogen	(50)	(133)	(60)
Suspended solids	34	91	41

Flow = 0.014 Cubic meters/sec
0.320 Million gallons/day

Table 17. DISCHARGE DATA OF THE FAIRMONT TREATMENT PLANT (PRIMARY)--M-6 (RIVER KILOMETER POINT = 11.52)

Parameters	Concentration (mg/ℓ)	Load (lb/day)	Load (kg/day)
BOD	49	278	126
Kjeldahl nitrogen	(20)	(113)	(51)
Ammonia nitrogen	(28)	(159)	(72)
Phosphorus	(10)	(56)	(26)
Total coliforms	2,961 mpn/100 ml	--	--
Total dissolved solids	334	1,898	859
Total nitrogen	(50)	(284)	(128)
Suspended solids	38	216	98

Flow = 0.0298 Cubic meters/sec
0.68 Million gallons/day

Table 18. DISCHARGE DATA OF THE DULUTH MAIN TREATMENT PLANT (PRIMARY)--M-7 (RIVER KILOMETER POINT = 5.31)

Parameters	Concentration (mg/ℓ)	Load (lb/day)	Load (kg/day)
BOD	76	11,586	5,248
Kjeldahl nitrogen	17.1	2,607	1,181
Ammonia nitrogen	(28)	(4,268)	(1,933)
Phosphorus	5.5	838	379
Total coliforms	7,797 mpn/100 ml	--	--
Total dissolved solids	329	50,154	22,720
Total nitrogen	(47.5)	(7,241)	(3,280)
Suspended solids	57	8,689	3,936

Flow = 0.7994 Cubic meters/sec
18.25 Million gallons/day

Table 19. DISCHARGE DATA OF THE SUPERIOR SEWAGE TREATMENT PLANT (PRIMARY)--M-8
(RIVER KILOMETER POINT = 497 FROM THE SUPERIOR ENTRY)

Parameters	Concentration (mg/ℓ)	Load (lb/day)	Load (kg/day)
BOD	90	2,758	1,249
Kjeldahl nitrogen	(20)	(612)	(277)
Ammonia nitrogen	(28)	(858)	(389)
Phosphorus	(10)	(306)	(138)
Total coliforms	(2,000 mpn/100 ml)	--	--
Total dissolved solids	(320)	(9,807)	(4,442)
Total nitrogen	(50)	(1,532)	(694)
Suspended solids	67	2,053	930

Flow = 0.1607 Cubic meters/sec
3.67 Million gallons/day

INDUSTRIAL DISCHARGES

The major industrial discharges along the St. Louis River main stream in the study area include those from the Conwed Corporation, Northwest Paper Company, U.S. Steel Corporation, Superwood Corporation, and Superior Fiber Product, Inc. These sources along with their code numbers and locations are listed in Table 20. Industries which discharge waste into local sewage systems or tributaries are not included in this category. The Diamond National Corporation discharges its wastes into the Cloquet sewage system, and the Continental Oil Company discharges its waste into the Silver Creek, one of the tributaries.

Characteristics of industrial discharges are presented in Tables 21 through 25. These data were synthesized from NPDES applications, the Western Lake Superior Sanitary District report entitled "Water Quality Management Plan: Inventory of Existing Waste Sources,"[3] and Point Source Survey Reports furnished by U.S. EPA - Minnesota-Wisconsin District Office.

SHIPPING WASTES

Shipping wastes consist of sanitary wastes, bilge water, and ballast water. These wastes differ in pollutant loadings and types, and are discharged into a shipping channel at varying rates, at irregular intervals.

Most of the available information concerning shipping wastes in the Duluth-Superior Harbor area is collected in a report prepared by the Environmental Quality Systems for the Upper Great Lakes Regional Commission and entitled Duluth-Superior Harbor Pollution Control Program.[4] This report is basically a compilation of data presently available from various agencies involved in research concerning shipping wastes. The report contains detailed presentations of data concerning shipping operations in the area. These data include frequency of visits, travel time, vessel visit patterns, length of stay, crew size, vessel size, cargo and waste characteristics, and available dockside facilities. Since the vessels discharge wastes at the various docks within the harbor, these docks may be considered point sources of wastes. The location of these docks and the amount of each type of waste generated at the respective docks are presented in Table 26 and Figure 3.

Vessel traffic patterns, and the characteristics of sanitary wastes, bilge water, and ballast water are presented below.

Table 20. INDUSTRIAL DISCHARGES

No.	Name	Location: Latitude / Longitude	Distance[a] Km (mile)
I-1	Conwed Corporation	46 43 30 92 28 00	52.02 (32.33)
I-2	Northwest Paper Company	46 43 33 92 25 44	48.11 (29.90)
I-3	U.S. Steel Corporation	46 40 33 92 12 02	19.00 (11.81)
I-4	Superwood Corporation	46 46 25 92 06 25	0.59 (0.37)
I-5	Superior Fiber Products, Incorporated	46 44 20 92 04 52	6.48 (4.03)[b]

a/ Unless otherwise indicated, the distance is measured upstream from the Duluth entry.

b/ Measured from the Superior entry.

Table 21. EFFLUENT CHARACTERISTIC OF CONWED CORPORATION (CLOQUET)--I-1
(RIVER KILOMETER POINT = 50.02)

Parameters	Concentration (mg/ℓ)	Load (lb/day)	Load (kg/day)
BOD	1,050	12,134	5,498
Kjeldahl nitrogen	6.5	75.1	34
Ammonia nitrogen	2.4	27.7	12.6
Phosphorus	2.1	24.3	11.0
Total coliforms	(1,000,000,000) (mpn/100 ml)	--	--
Total dissolved solids	1,290	14,908	6,753
Total nitrogen	15.9	183.7	83.2
Suspended solids	--	8,000	3,624

Flow = 0.0606 Cubic meters/sec
= 1.3836 Million gallons/day

Table 22. EFFLUENT CHARACTERISTICS OF NORTHWEST PAPER COMPANY (CLOQUET)--I-2 (RIVER KILOMETER POINT = 48.11)

Parameters	Concentration (mg/ℓ)	Load (lb/day)	Load (kg/day)
BOD	400	90,544	41,016
Kjeldahl nitrogen	5.2	1,177	533
Ammonia nitrogen	0.9	204	92
Phosphorus	0.2	45	21
Total coliforms	(22,000,000 mpn/100 ml)	--	--
Total dissolved solids	948	214,590	97,209
Total nitrogen	9.3	2,105	953
Suspended solids	--	34,000	--

Flow = 1.187 Cubic meters/sec
27.1 Million gallons/day

Table 23. EFFLUENT CHARACTERISTICS OF U.S. STEEL CORPORATION (DULUTH WORKS)--I-3 (RIVER KILOMETER POINT = 19.00)

Parameters	Concentration (mg/ℓ)	Load (lb/day)	Load (kg/day)
BOD	51.7	6,736	3,051
Kjeldahl nitrogen	55	7,166	3,246
Ammonia nitrogen	53	6,905	3,128
Phosphorus	0.086	11.2	5.1
Total coliforms	(2,070 mpn/100 ml)	--	--
Total dissolved solids	228	29,705	13,456
Total nitrogen	108.4	14,123	6,397
Suspended solids	28	36,480	1,653

Flow = 0.6832 Cubic meters/sec
15.60 Million gallons/day

Table 24. EFFLUENT CHARACTERISTICS OF SUPERWOOD CORPORATION (DULUTH)--I-4 (RIVER KILOMETER POINT = 0.59)

Parameters	Concentration (mg/ℓ)	Load (lb/day)	Load (kg/day)
BOD	3,200	16,049	7,270
Kjeldahl nitrogen	8.3	41.6	18.9
Ammonia nitrogen	4.5	22.5	10.2
Phosphorus	1.5	7.5	3.4
Total coliforms	(9,200 mpn/100ml)	--	--
Total dissolved solids	3,400	17,052	7,724
Total nitrogen	13.4	67.2	30.4
Suspended solids	--	1,500	679

Flow = 0.263 Cubic meters/sec
0.600 Million gallons/day

Table 25. EFFLUENT CHARACTERISTICS OF SUPERIOR FIBER PRODUCTS (SUPERIOR)--I-5 (RIVER KILOMETER POINT = 6.48 MEASURED FROM THE SUPERIOR ENTRY)

Parameters	Concentration (mg/ℓ)	Load (lb/day)	Load (kg/day)
BOD	4,500	24,800	11,234
Kjeldahl nitrogen	2.81	15.5	7.0
Ammonia nitrogen	1.4	7.7	3.5
Phosphorus	0.06	0.3	0.1
Total coliforms	(9,200 mpn/100 ml)	--	--
Total dissolved solids	4,900	27,000	12,333
Total nitrogen	5.15	28.4	12.9
Suspended solids	--	800	362

Flow = 0.0289 Cubic meters/sec
0.66 Million gallons/day

Table 26. DOCK FACILITIES AND QUANTITY OF WASTE GENERATION ON A YEARLY BASIS[a]/

Dock No.	Name	Volume of Shipping Wastes, in Millions of Liters (gal.) Per Year		
		Body Wastes	Ballast Water	Bilge Water
1	Fraser Shipyards			
2	Great Lakes Storage and Contracting, Superior	0.575 (0.152)		15 (4)
3	Continental Elevator	0.712 (0.188)	314 (83)	64 (17)
4	Huron Cement, Superior	0.337 (0.089)		30 (8)
5	Marine Fueling		2 (0.6)	
6	Cutler-Laliberte	0.488 (0.129)		45 (12)
7	Osborne-McMillan Elevators (M&O)	0.269 (0.71)	117 (31)	23 (6)
8	Burlington Northern (1,2,4, and Old NP)	8.020 (2.119)	3,569 (943)	719 (190)
9	C. Reiss, Superior	0.379 (0.100)		34 (9)

Table 26. (Continued)

Dock No.	Name	Volume of Shipping Wastes, in Millions of Liters (gal.) Per Year		
		Body Wastes	Ballast Water	Bilge Water
10	Coast Guard			
11	Industrial Welding and Machinery			
12	Lakehead Boat Basin			
13	Drill's Arena Marina			
14	Huron Cement,[b/] Duluth	0.337 (0.089)		30 (8)
15	Great Lakes Storage and Contracting, Duluth	0.575 (0.152)		15 (4)
16	Zenith Dredge			
17	Great Lakes Towin			
18	Cutler-Magner Salt	0.068 (0.018)		8 (2)
19	General Mills	0.401 (0.106)	174 (46)	34 (9)
20	Cargill B	1.393 (0.168)	284 (75)	57 (15)

Table 26. (Continued)

Dock No.	Name	Volume of Shipping Wastes, in Millions of Liters (gal.) Per Year		
		Body Wastes	Ballast	Bilge Water
21	Hallett Dock No. 3	0.193 (0.051)		15 (4)
22	Capitol Elevator (4 and 6)	0.942 (0.249)	415 (110)	83 (22)
23	Hyman-Michaels	0.091 (0.024)		8 (2)
24	Cargill C & D	0.878 (0.208)	348 (92)	72 (19)
25	Arthur M. Clure	2.956 (0.781)		68 (18)
26	Farmers Union (1 and 2)	1.431 (378)	636 (168)	129 (34)
27	Paper Calmenson, Superior	0.114 (0.030)	- -	8 (2)
28	Globe Elevator	0.712 (0.188)	314 (83)	64 (17)
29	Burlington Northern Elevator	0.014 (0.268)	450 (119)	91 (24)
30	Murphy Oil	0.326 (0.086)	35 (9.21)	11 (3)
31	Great Lakes Coal and Dock	0.420 (0.111)	- -	45 (12)

Table 26. (Concluded)

Dock No.	Name	Volume of Shipping Wastes, in Millions of Liters (gal.) Per Year		
		Body Wastes	Ballast	Bilge Water
32	Standard Oil	0.197 (0.052)	261 (69)	11 (3)
33	Duluth Dock and Transport		0 (0)	0 (0)
34	Hallett Dock No. 6	0.269 (0.071)	- -	23 (6)
35	Drill's Marina			
36	C. Reiss, Duluth	0.579 (0.153)		53 (14)
37	Hallett Dock No. 5	0.670 (0.177)		61 (16)
38	Duluth, Missable 8 Iron Range (5, 6)	11.964 (3.161)	5,322 (1,406)	1,075 (284)
39	Paper Calmenson, Duluth	0.114 (0.030)		8 (2)

a/ Information Source: "Duluth-Superior Harbor Pollution Control Program," Environmental Quality Systems, Incorporated, Washington, D.C., 1971.

b/ No more discharge.

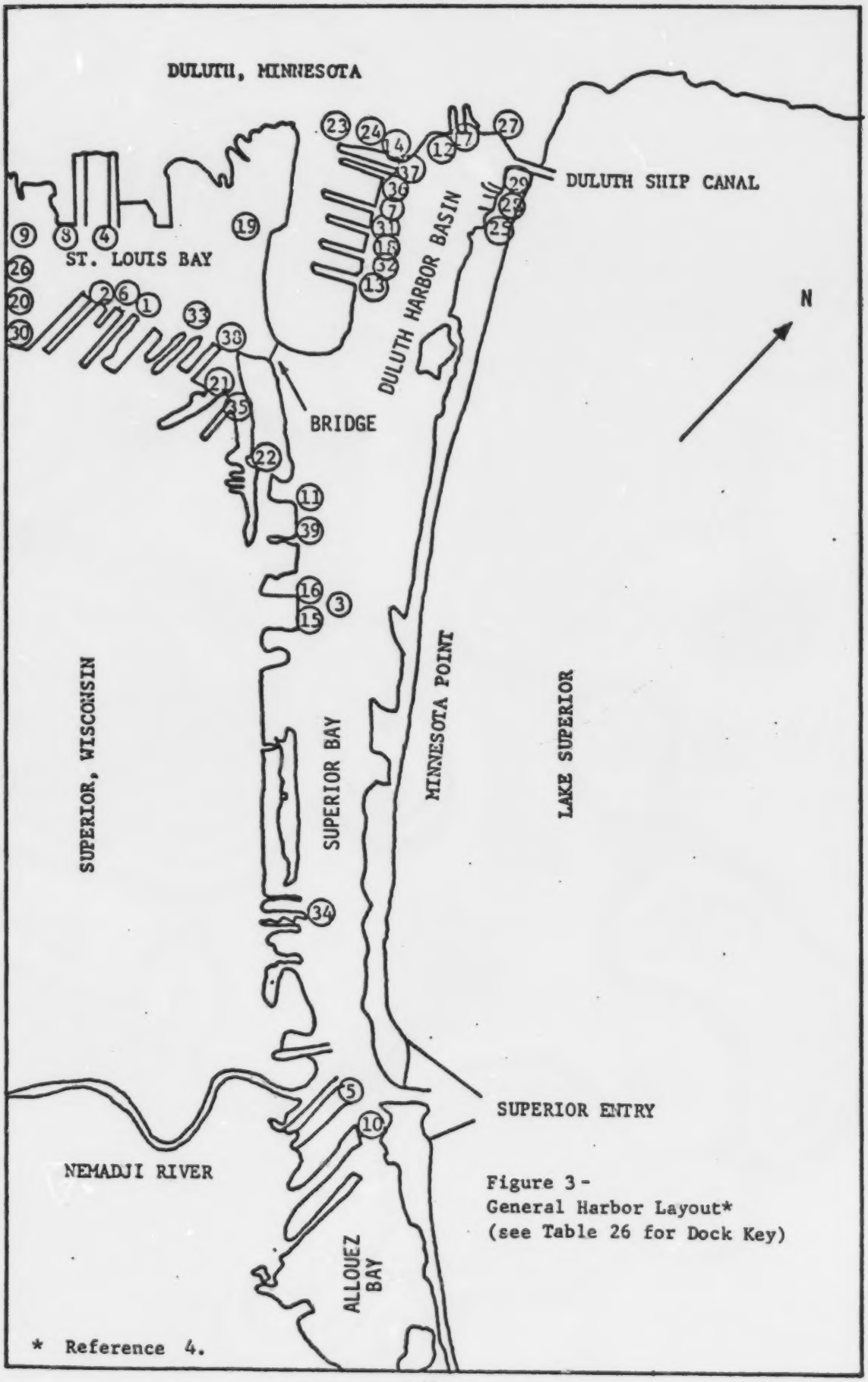


Figure 3 -
General Harbor Layout*
(see Table 26 for Dock Key)

* Reference 4.

Vessel Traffic Analysis

Vessel waste generation depends on the nature of vessel traffic within a harbor. An analysis of vessel traffic in the Duluth-Superior Harbor was performed by the U.S. Corps of Engineers, St. Paul District.[4/] The analysis includes number of vessels, visiting location, cargo type, seasonal, monthly and daily traffic fluctuations; length of stay in the harbor, crew size, and facilities available for waste disposal.

As part of the results from that study, Figure 4 shows the variation in vessel visits by month for the period 1959-1970, inclusive. This figure indicates quite clearly that seasonal variations in vessel traffic are very significant. May, June and July represent the peak vessel traffic about 140% of the average.

Vessel Sanitary Wastewater

Using surveys of published literature, the following estimates were made of the quantity and characteristics of vessel sanitary wastewater: (Table 27)

Table 27. CHARACTERISTICS OF VESSEL SANITARY WASTES

Average volume	30 gal/capita/day
Peak volume	40 gal/capita/day
Total coliform bacteria, 100 ml, arithmetic average	1.6×10^6
Fecal coliform bacteria, 100 ml, arithmetic average	7.3×10^5
BOD_5, 20°, mg/ℓ	108
Settleable solids, mg/ℓ	85
Nitrogen, ammonia, mg/ℓ as N	8.8
Nitrogen, Kjeldahl, mg/ℓ as N	66
Total phosphate, mg/ℓ as PO_4	22

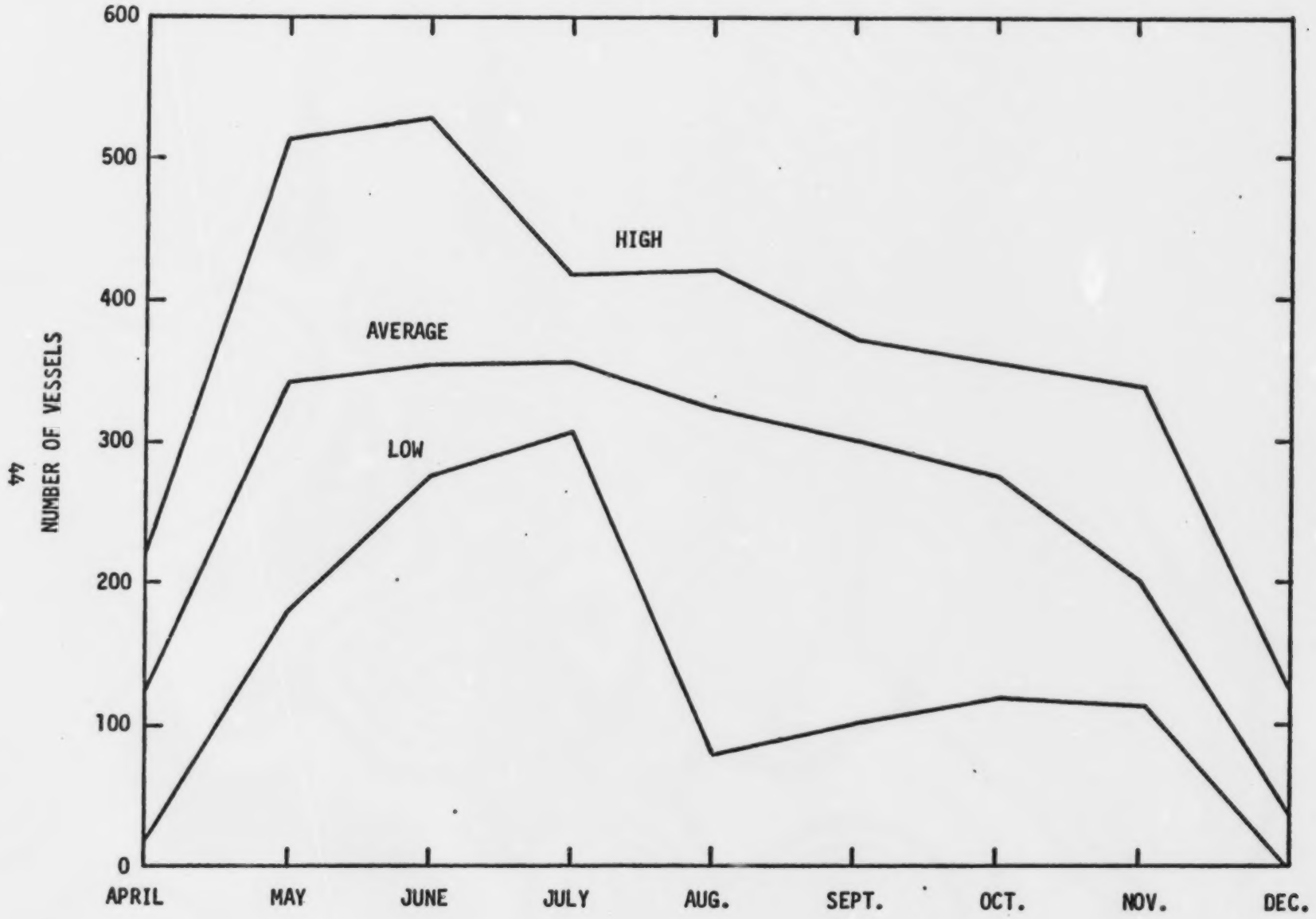


Figure 4. Lake Vessel Monthly Visits at the Duluth-Superior Harbor for 1959-1970 [4/]

Of the total sanitary wastewater load in the Duluth-Superior Harbor, approximately two-thirds is carried to the municipal sewer system through three dock facilities. The remaining one-third, approximately 3.3 million gallons per year, is disposed of by sewer, septic tank, holding tank, or dumping into the harbor.

Bilge Water

Bilge water is that water due to leaks and spills which collects in the lower part of a ship. Bilge water may be contaminated with oily solvents, rust, and scale, and a myriad of other materials, and is commonly recognized as a highly polluted material.

Essentially no information is available pertinent to the quality of bilge water generated in the Duluth-Superior Harbor. Assumed bilge water pollutant characteristics are presented in Table 28.

Table 28. ASSUMED CHARACTERISTICS OF BILGE WATER

Parameters	Concentration (mg/ℓ)
BOD	100
Kjeldahl nitrogen	10
Ammonia nitrogen	10
Phosphorus	15
Total coliforms	1,000,000 mpn/100 ml
Total dissolved solids	300
Total nitrogen	22
Suspended solids	50

Ballast Water

Ballast water is used extensively in commercial operations at Duluth-Superior to compensate for underloading of vessels. This is especially true for those vessels which must pass under the aerial lift bridge over the Duluth Canal.

Characteristics of ballast water depend on the type of vessel and the source of the water. In the absence of measured information, the quality data presented in Table 29 were used, together with estimates of ballast water volumes, to make a first approximation of the pollutional impact of ballast water on the harbor.

Summary of Pollutant Loading from Shipping

By combining information on quantity (Table 26), and characteristics (Tables 27, 28, and 29), and seasonal variations of vessel traffic (Figure 4), water pollutant loading for the summer months (May-July), and early winter (November) were calculated. Table 30 presents the results.

Table 29. ASSUMED CHARACTERISTICS OF BALLAST WATER

Parameters	Concentration (mg/ℓ)
BOD	11
Kjeldahl nitrogen	15
Ammonia nitrogen	15
Phosphorus	0.6
Total coliforms	900,000 mpn/100 ml
Total dissolved solids	810
Total nitrogen	342
Suspended solids	30

Table 30. LOADINGS OF SHIPPING WASTE

Parameters	Loading			
	lb/day		kg/day	
	May-July	November	May-July	November
BOD	1,895	1,051	357	476
Kjeldahl nitrogen	2,302	1,277	1,043	579
Ammonia nitrogen	2,302	1,277	1,043	579
Phosphorus	124	68	56	31
Total coliforms	900,000 mpn/100 ml			
Total dissolved solids	123,787	68,701	56,076	31,122
Total nitrogen	5,247	2,912	2,376	764
Suspended solids	4,671	2,592	2,116	1,174
Flow (10^6 gal/day)	18.47	10.25	--	--

SECTION V

LOAD ALLOCATION STUDY

In this task, load allocation analysis was conducted using the St. Louis River water quality simulation model. The analysis includes projection of water quality levels of the study area, if 1977 effluent limits were put into effect, determination of allowable industrial discharges so that specific water quality standards will be met, and projections for a discharge profile configuration which has only three major points of discharge. The latter configurations are basically the regional plan involving construction of a regional treatment plant.

THE ST. LOUIS RIVER BASIN MODEL

The St. Louis River Basin Model was developed by MRI under a separate contract (EPA Contract No. 68-01-1853). In developing this model, the Columbia River Model[5] was utilized, in a modified form, calibrated and verified for the basin using historical hydrologic and water quality data. Documentation of this model is presented in Reference 1.

The model has the capability to predict the concentrations of the following water quality constituents:

Conservative:

- Total nitrogen
- Total dissolved solids

Nonconservative:

- Phosphorus (first order kinetics for sediment transfer)
- Coliforms (first order kinetics)
- Ammonia (first order kinetics)
- Nitrite (first order kinetics)
- Carbonaceous biochemical oxygen demand

- Dissolved oxygen (including benthic uptake, with carbonaceous BOD utilization, ammonia oxidation, nitrite oxidation, algal respiration and production, and atmospheric and dam reaeration).

In the model, the six impoundments between Cloquet and Fond du Lac are treated as nonstratified systems simulated by two-dimensional branched networks. The Minnesota Power and Light diversion from Thomson Reservoir through Forbay Lake is included in the simulation. The wide sections of the lower part of the system, namely the bays and inlets, also employ the branched network scheme. All tributaries to the system are treated as point waste sources.

The following sections present a discussion of the schematization of the river and verification of the model.

Schematization of the St. Louis River

In developing the water quality model, the stream and bay are represented by channels and junctions. These form a network which can be analyzed by a digital computer. The channel-junction method consists of dividing the natural channel into a finite number of sections. Each of these sections contains a finite volume of water. These sections are assumed to be uniform (or completely mixed) at a given instant in time in all their properties. These discrete sections of the water body are referred to as junctions.

Channels are the interfaces between junctions, i.e., water flow and the consequent transfer of properties from one junction to another. Computationally, the channel is treated as a uniform, rectangular channel between junction midpoints.

Various properties are associated with either a channel or a junction. The properties of a channel are:

1. Flow
2. Velocity
3. Dispersion coefficient
4. Manning Roughness coefficient
5. Cross-sectional area
6. Depth
7. Width
8. Length

The properties of a junction are:

1. Volume
2. Surface area
3. Constituent concentrations
4. Temperature
5. Inflows
6. Diversions
7. Reaeration rate
8. Photosynthesis - respiration rate
9. Benthic uptake rate
10. CBOD decay rate
11. Reaction rates for other pollutants
12. Constituent masses
13. Inflow concentrations

The total network of the modeled area consists of 242 junctions, each of which is an arbitrarily-shaped area centered about a junction point; the junctions are connected by 276 channels. Details of the schematization are shown in Figures 5a, b, c, d, and e. In these figures, junction numbers are given for a dot which denotes the center point of a junction, and channel numbers (in parentheses) are given for each line connecting two junctions. Code letter-numbers in these figures are used to indicate point discharges, including "I-" for industrial discharges, "M-" for municipal wastes, and "T-" for tributaries.

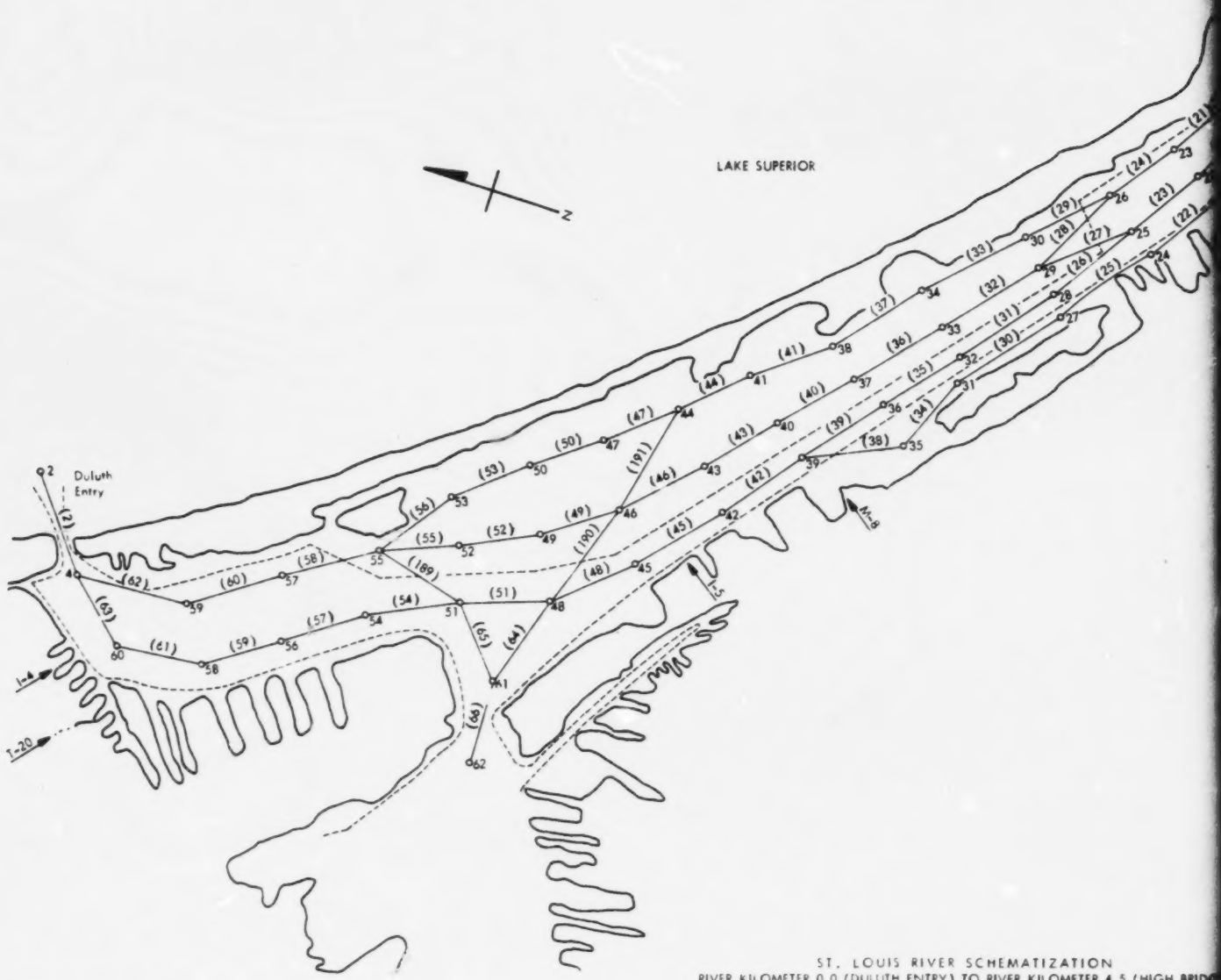
The schematization was prepared primarily from the U.S. Corps of Engineers Lake Survey Chart No. 366, and the U.S. Geological Survey quadrangle maps.

The selection of junction points and the distances between points is based upon an initial choice of integration period for numerical solution of differential equations and an average channel depth between junctions. For the St. Louis River study area, the channel length selected for schematization ranges from 420 m to 1,100 m.

Upon completion of the schematization, pertinent input data for the model were obtained for each junction and each channel.

Each junction has the following input data: a number, numbers of channels (from one to five) connected to it, surface area (square meters), and an initial head (meters). In addition, when tributaries or point discharges are located in a junction, the quantity and quality of the discharge are input for that junction.

Each channel has as input data: a number, numbers of two junctions connected to it, width (meters), depth (meters), initial streamflow velocity (meters/sec), and Manning Roughness coefficient.



ST. LOUIS RIVER SCHEMATIZATION
RIVER KILOMETER 0.0 (DULUTH ENTRY) TO RIVER KILOMETER 4.5 (HIGH BRIDG

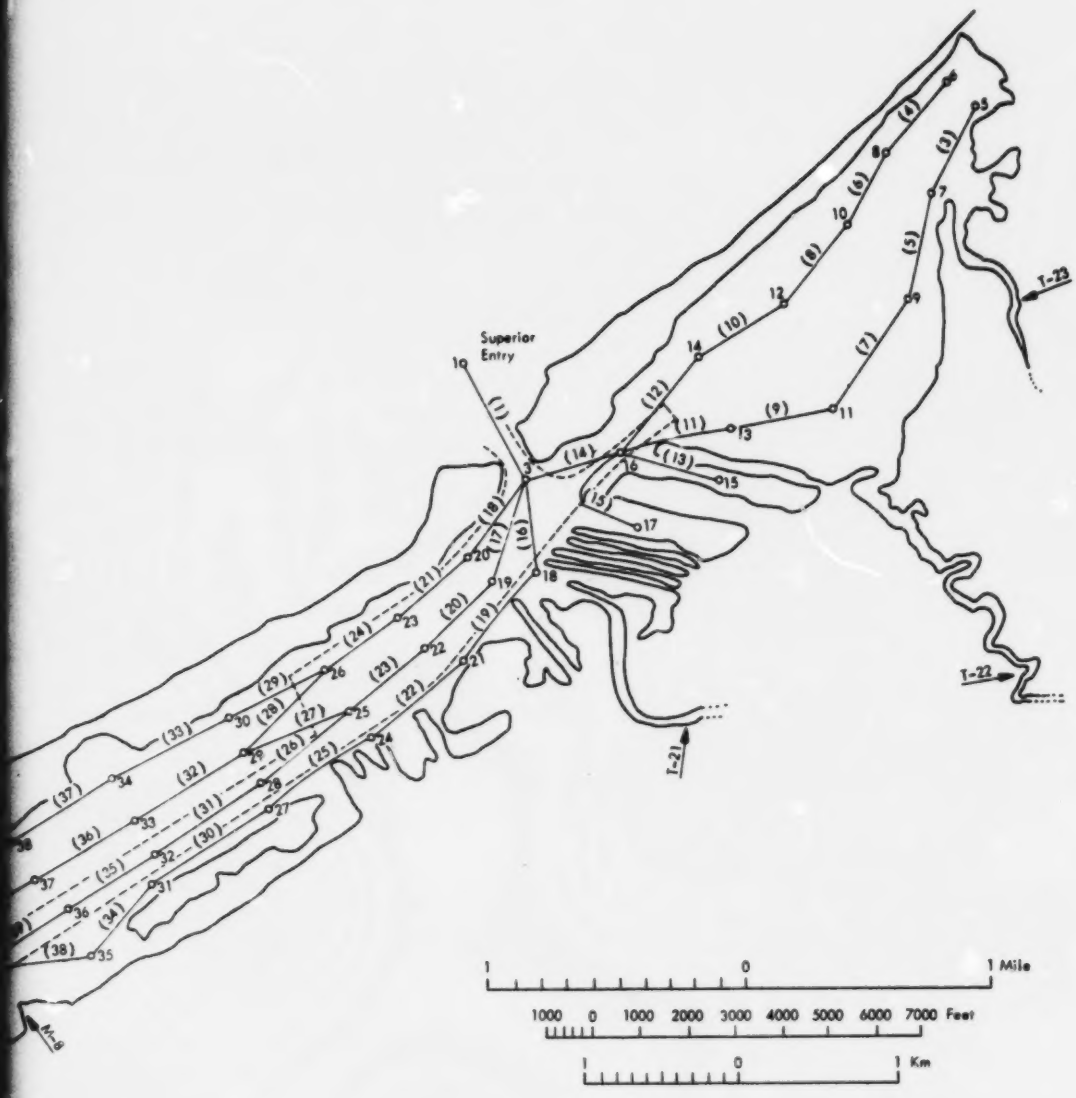
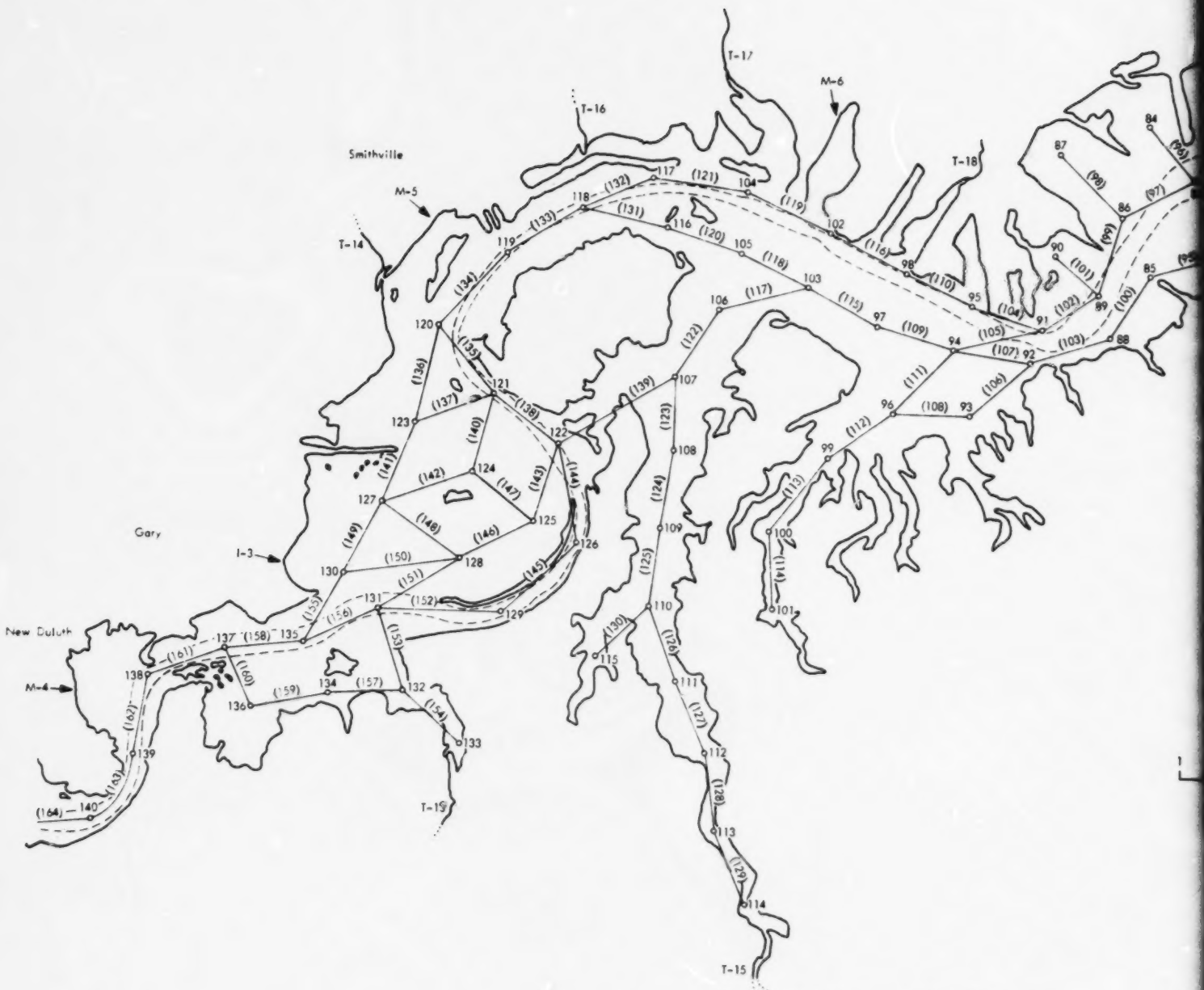


Figure 5a

LOUIS RIVER SCHEMATIZATION
(DULUTH ENTRY) TO RIVER KILOMETER 4.5 (HIGH BRIDGE)



ST. LOUIS RIVER SCHEMATIZATION
RIVER KILOMETER 4.5 (HIGH BRIDGE) TO RIVER KILOMETER 23.1 (OLIVER BRIDGE)

1 0 1 Mile

1000 0 1000 2000 3000 4000 5000 6000 7000 Feet

1 0 1 Km

Figure 5b

S RIVER SCHEMATIZATION
IDGE) TO RIVER KILOMETER 23.3 (OLIVER BRIDGE)

ST. LOUIS RIVER SCHEMATIZATION
RIVER KILOMETER 23.1 (OLIVER BRIDGE) TO RIVER KILOMETER 44.9 (SCANLON)

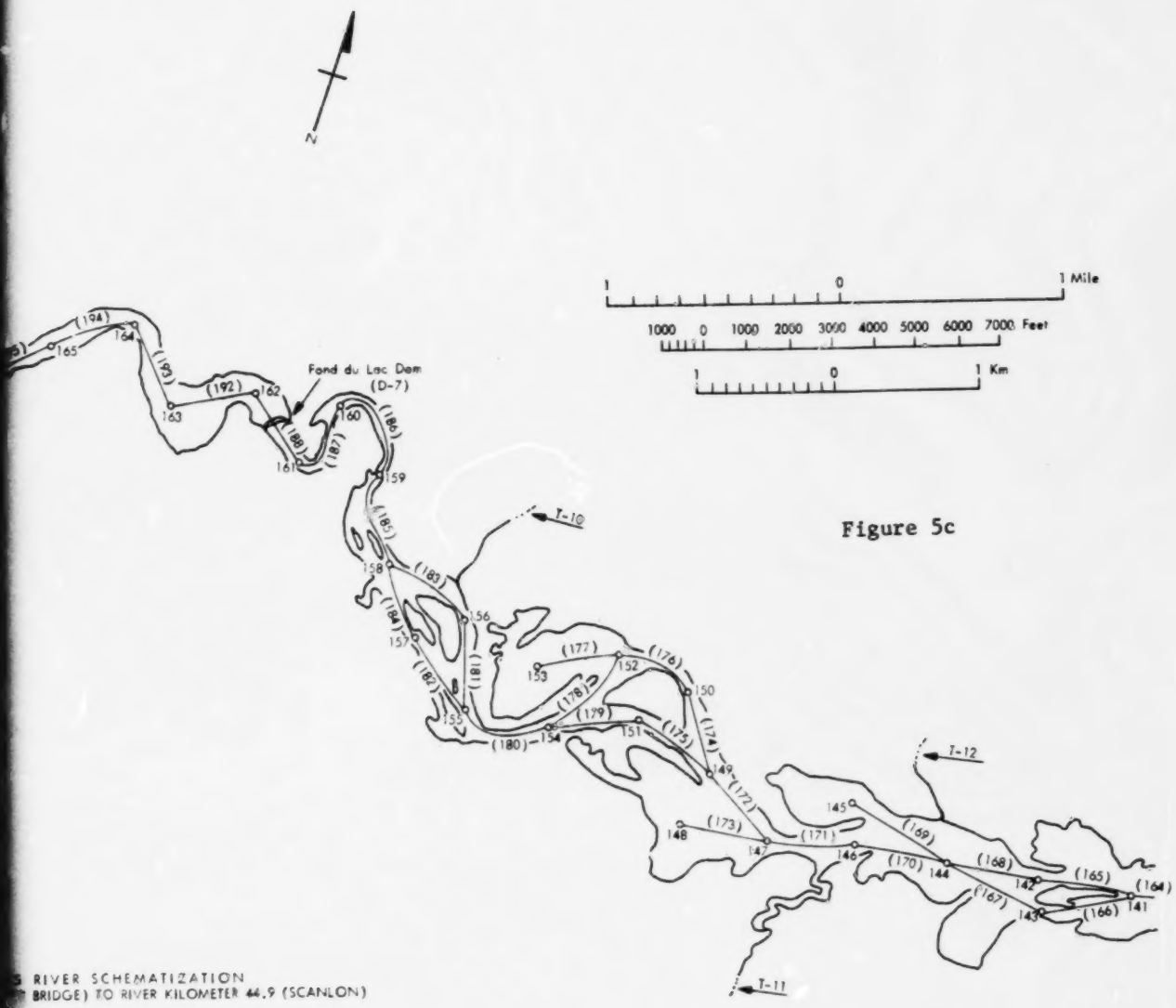
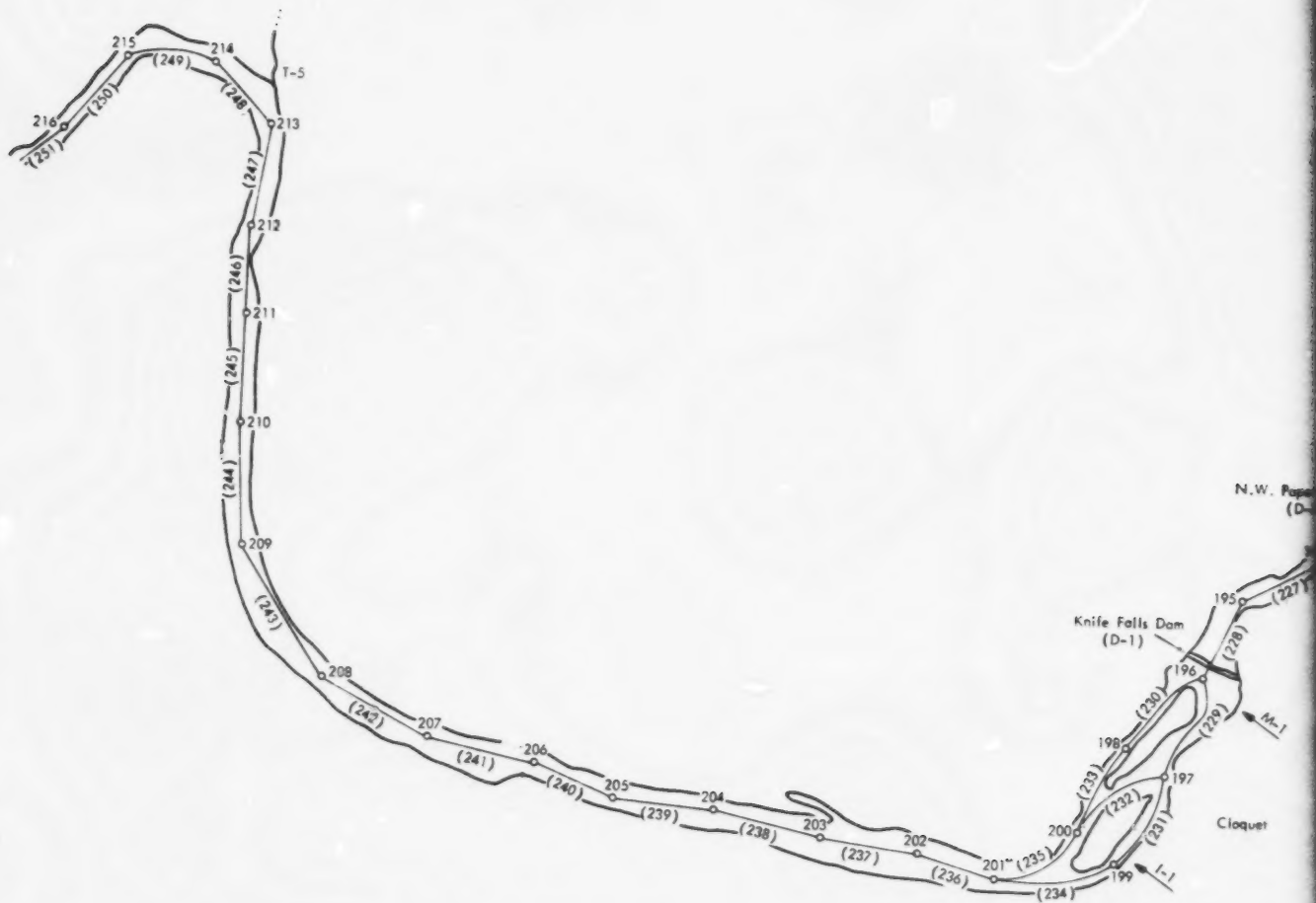


Figure 5c

S RIVER SCHEMATIZATION
BRIDGE) TO RIVER KILOMETER 44.9 (SCANLON)

54



ST. LOUIS RIVER SCHEMATIZATION
RIVER KILOMETER 44.9 (SCANLON) TO RIVER KILOMETER 64.0 (BREVATOR)

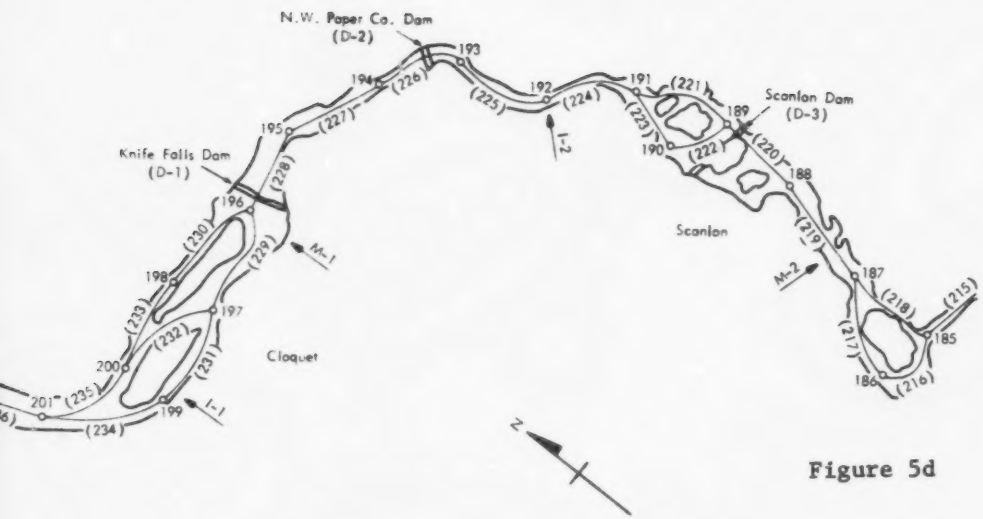


Figure 5d

SCHEMATIZATION
O RIVER KILOMETER 64.0 (BREVATOR)

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ST. LOUIS RIVER SCHEMATIZATION
RIVER KILOMETER 64.0 (BREVATOR) TO RIVER KILOMETER 81.6 (BROCKSTON)

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best available copy.

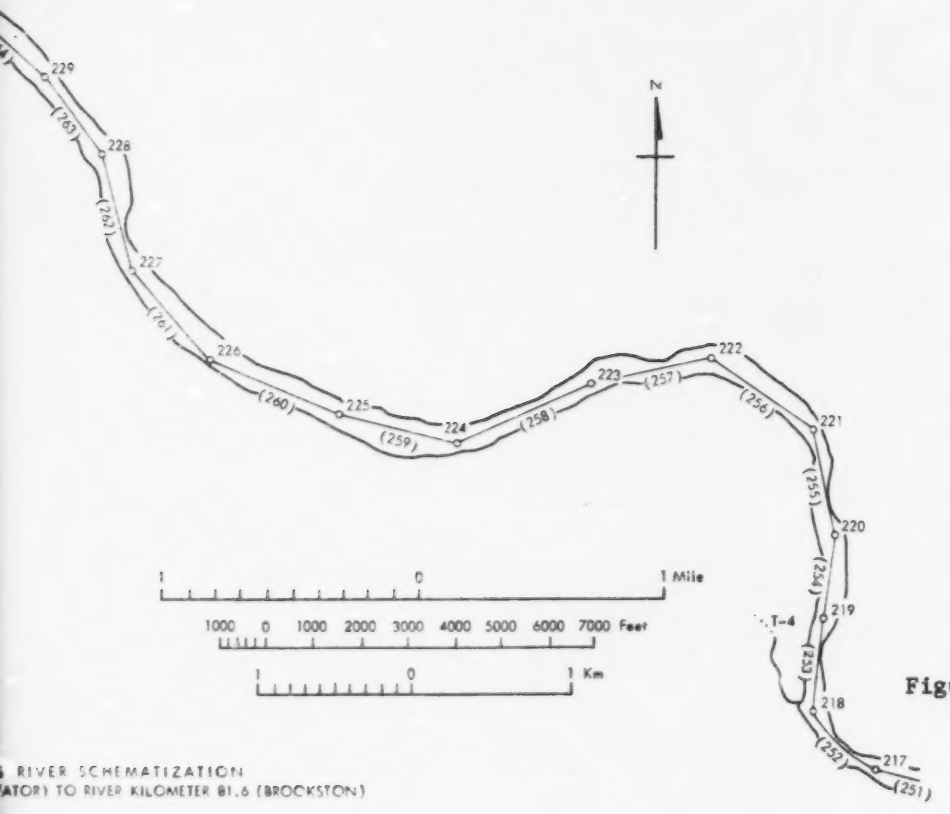

Figure 5e

RIVER SCHEMATIZATION
ATOR) TO RIVER KILOMETER 81.6 (BROCKSTON)

Verification of the Model

There are many factors which affect the concentration of pollutants in natural streams. Dilution and advection reduce the concentration of pollutants and transport contaminants downstream from their sources, and they are affected by the physical and chemical characteristics of the wastewater itself and the river flow. In addition, the natural biological activity of the water environment results in the reduction of organic compounds to end products of a stable nature. Atmospheric oxygen replenishment, the photosynthetic activity of the green plants, algal respiration and benthal demands affect the dissolved oxygen concentration in the river. The water quality model, in essence, analytically abstracts the interrelationships of these factors and approximates (mathematically) the physical, chemical, and biological status of a river or estuary.

The factors which influence water quality, and measures of quality in streams such as BOD, dissolved oxygen and nutrients, can be grouped into two general categories. The first category consists of the geophysical characteristics of the stream and associated drainage areas. The cross-sectional area, depth, fresh water flow and temperature are examples of geophysical characteristics of streams. The second category encompasses chemical and biochemical reaction phenomena together with the sources and sinks of pollutional materials.

The procedure for developing models for water quality essentially consists of constructing a materials balance in mathematical terms, incorporating geophysical characteristics, the various reaction phenomena, and the sources and sinks of pollutants. A differential equation resulting from the mass balance depicts the interrelationships between the various factors which influence quality. Integration of the differential equation and evaluation of the appropriate boundary conditions yields equations which quantitatively relate the various factors to stream water quality.

For details of development, verification, and sensitivity analysis of the St. Louis River Model, the reader is referred to the final report of EPA Contract No. 68-01-1853,[1/] and to background documentation provided by Gallaway, Eyrom and Ditsworth,[5/] and Feigner and Harris.[6/]

Two flow periods were selected for simulation and verification of the model. They are: 12 July to 6 August 1973, and 26 November to 5 December 1973. These two periods were selected because of availability of flow and water quality data, and also because of relatively constant stream flow and water temperature, which are plotted by flow periods in Figures 6 and 7, respectively. The first simulation period (12 July to 6 August 1973)

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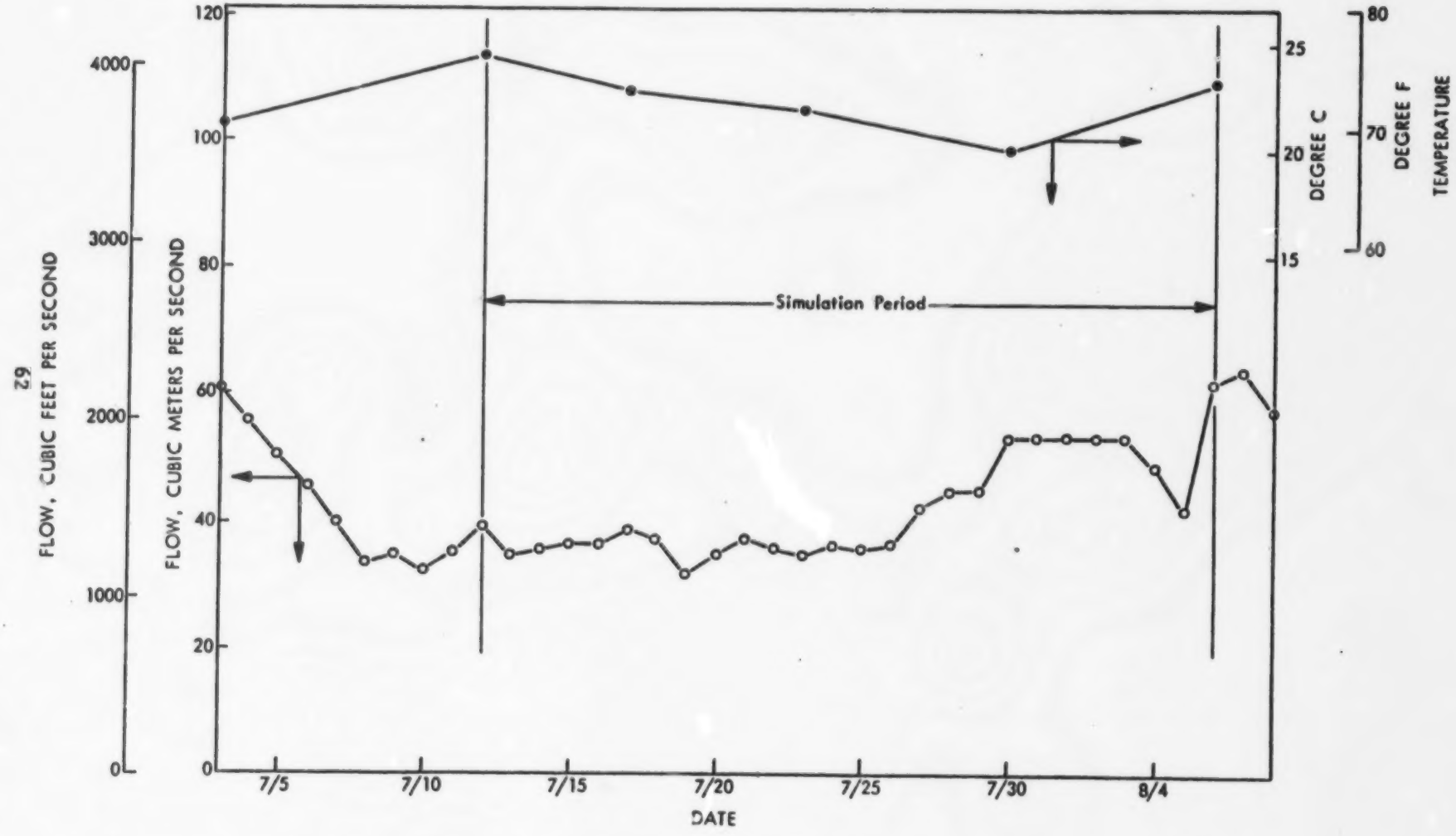

Figure 6. Stream Flow and Water Temperature of the First Simulation Period (Summer 1973)

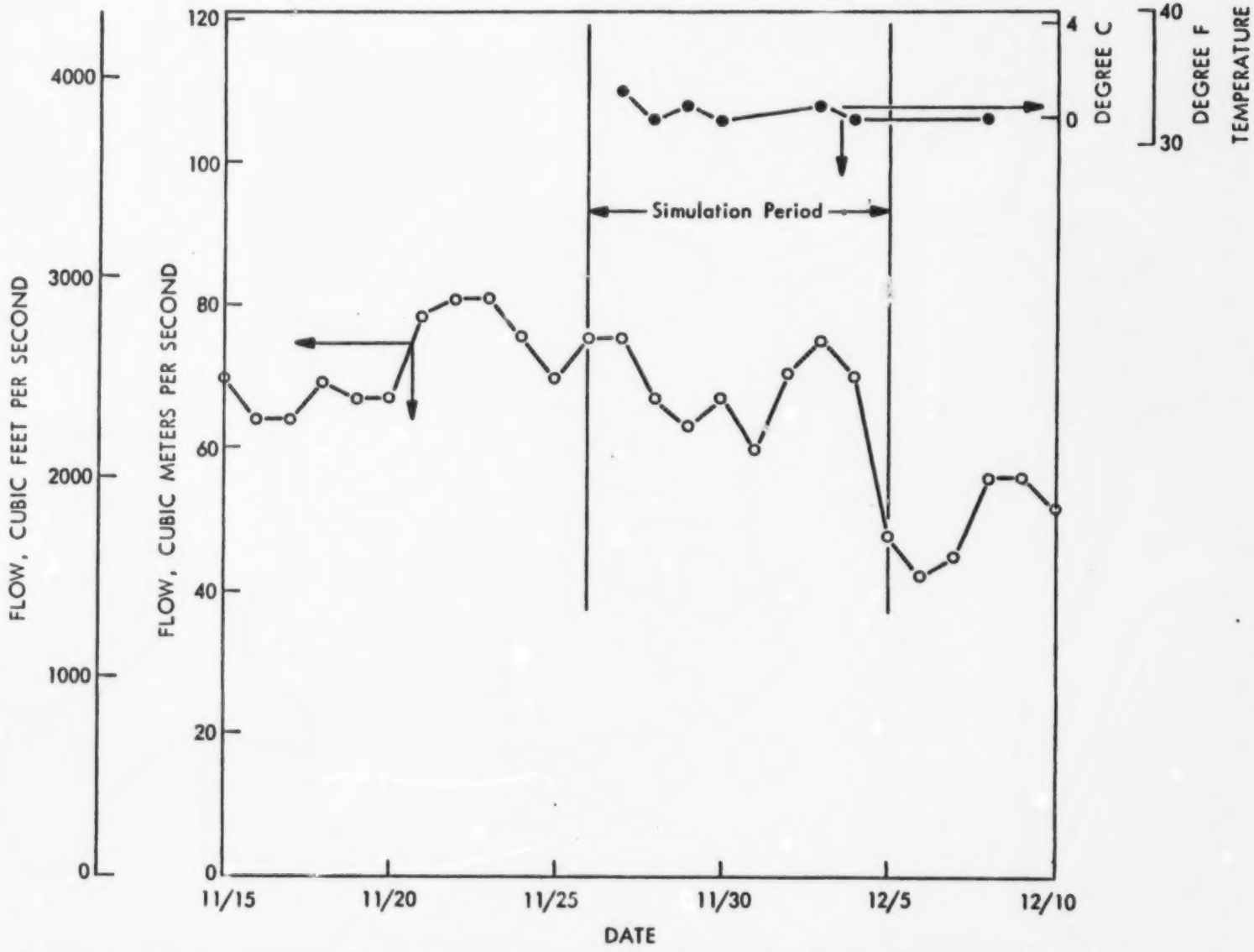

Figure 7. Stream Flow and Water Temperature of the Second Simulation Period (Winter 1973)

represents the summer low flow condition at 1,525 cfs (measured at Scanlon), with water temperatures ranging from 19.5 to 23.4°C. Water quality data for this period were collected by the Western Lake Superior Sanitary District. The second flow period covers the November-December 1973, sampling period. During the latter period, an intensive sampling program, including measurements of water quality, bottom sludge deposits, and stream flow, was conducted. Average stream flow during the period was 2,424 cfs, and temperatures ranged from 0.3 to 2.0°C.

After a fairly extensive calibration effort, the model has the capability to closely simulate water quality in the St. Louis River. The results of simulation are illustrated in Figures 8 and 9 for summer and winter flow periods.

In addition to DO and BOD, the verification study also included distribution of conservative substances (TDS, and total nitrogen), prediction of nutrients levels, and simulation of bacteria concentrations.[1/]

Numerous analyses were also conducted to determine the sensitivity of prediction to various model parameters such as the reaeration rate constants, stream flow, and river bottom friction coefficients.[1/]

It is important to point out that the model predictions are steady state values which result from utilization of mean values for waste loads, temperature, and inflows from tributaries and from the mainstream at Brookston. The model predictions also do not consider dilution effects from Lake Superior. The fact that the observed data may not be truly representative of steady state may account for certain of the apparent discrepancies in the figures.

LOAD ALLOCATION STUDY

In this program, the water quality model presented above was used to predict important parameters in the St. Louis River resulting from implementation of effluent guidelines. The predicted levels were compared with applicable water quality criteria. When criteria were violated, reduced loadings were assumed and water quality recalculated to determine what steps are necessary to achieve water quality goals for the river.

Water Quality Standards

Revised water quality standards for the St. Louis River were submitted by the Minnesota Pollution Control Agency and approved by EPA on 6 November 1973.[7/]

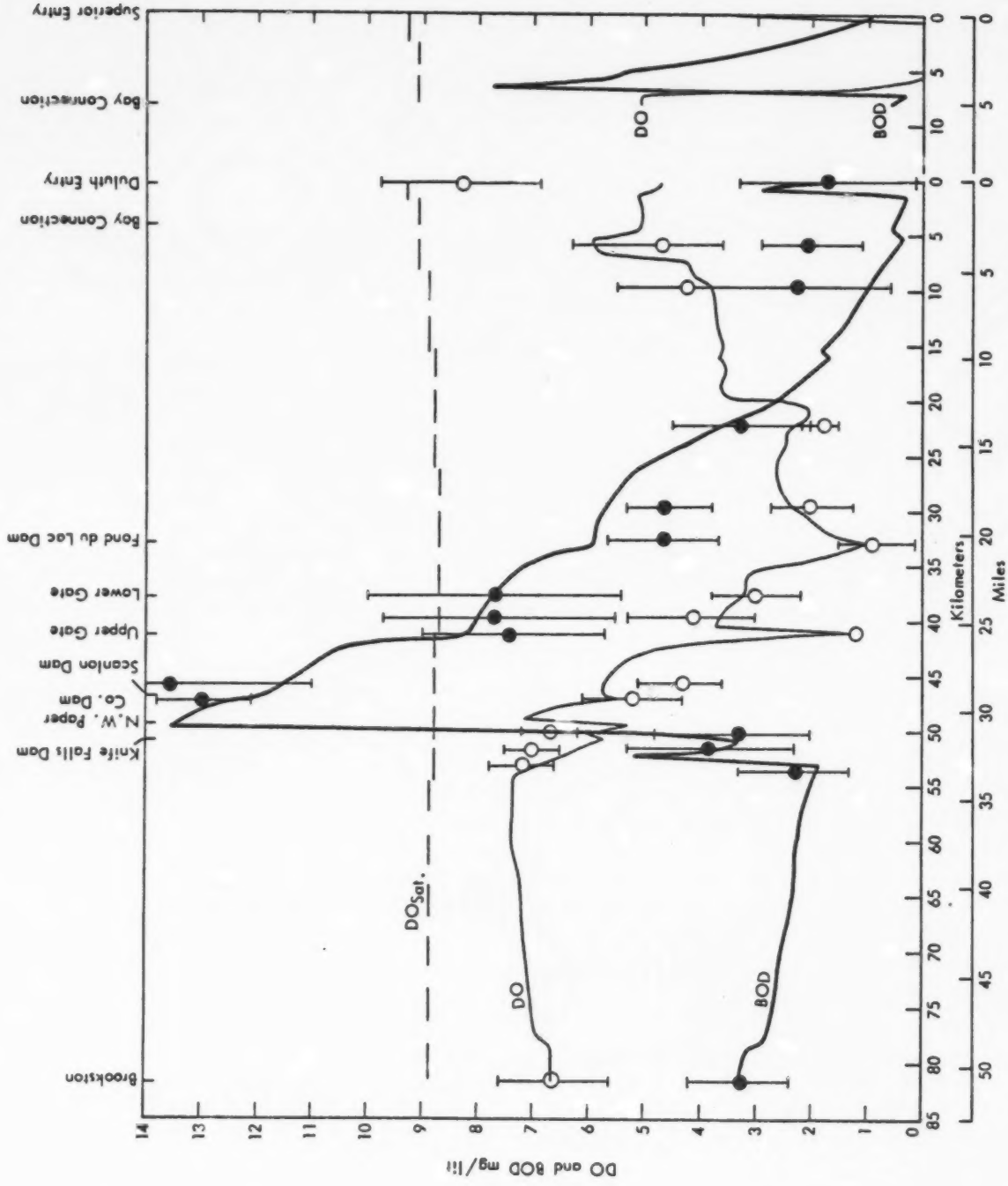

Figure 8. DO and BOD Profiles of the First (Summer 1973) Verification Period

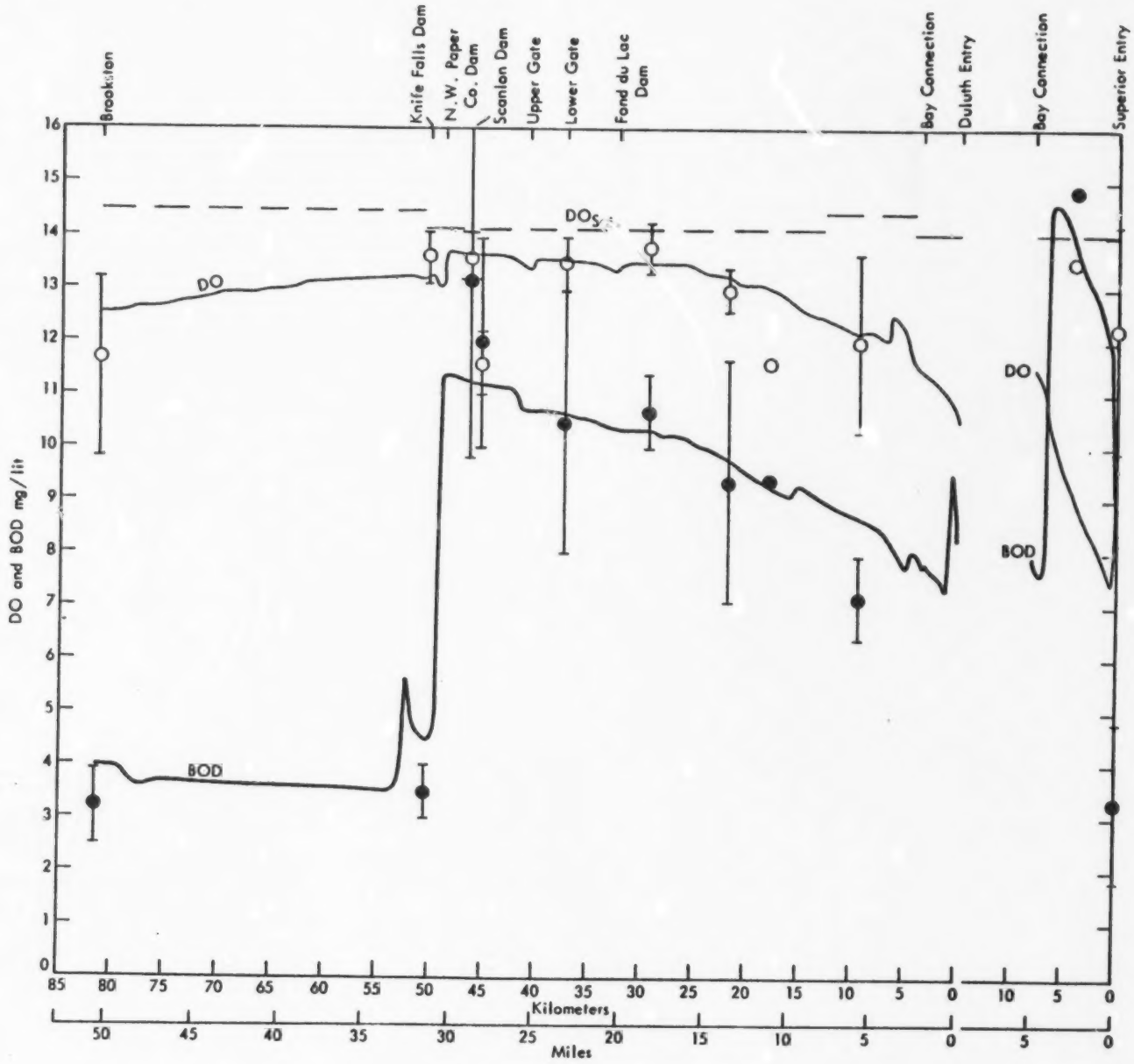

Figure 9. DO and BOD Profiles of the Second (Winter 1973) Verification Period

The Upper St. Louis River (Seven Beaver Lake outlet to Cloquet) is classified for 2B and 3B waters; the Lower St. Louis River (Cloquet to Clough Island) for 2C and 3B waters, and the bay area (Superior Bay and St. Louis Bay) for 2B and 3B.[6/]

The water quality criteria for 2B and 3B waters including the upper portion of the river (to Cloquet) and the bay area are:

Substance or Characteristic	Limit or Range
Dissolved oxygen	Not less than 6 mg/liter from April 1 through May 31, and not less than 5 mg/liter at other times.
Temperature	5°F above natural in streams and 3°F above natural in lakes, based on monthly average of the maximum daily temperature, except in no case shall it exceed the daily average temperature of 86°F.
Ammonia (N)	1 mg/liter.
Chromium (Cr)	0.05 mg/liter.
Copper (Cu)	0.01 mg/liter or not greater than one-tenth of the 96-hr TLM value.
Cyanides (CN)	0.02 mg/liter.
Oil	0.5 mg/liter.
pH value	6.5-9.0

Phenols	0.01 mg/liter and none that could impart odor or taste to fish flesh or other freshwater edible products such as crayfish, clams, prawns and like creatures. Where it seems probable that a discharge may result in tainting of edible aquatic products, bioassays and taste panels will be required to determine whether tainting is likely or present.
Turbidity value	25
Fecal coliform organisms	200 most probable number per 100 ml as a monthly geometric mean based on not less than five samples per month, nor equal or exceed 2,000 most probable number per 100 ml in more than 10% of all samples during any month.
Radioactive materials	Not to exceed the lowest concentration permitted to be discharged to an uncontrolled environment as prescribed by the appropriate authority having control over their use.

The criteria for the lower St. Louis River (Cloquet to Clough Island) which is classified for 2C and 3B waters, are:

Substances or Characteristic	Limit or Range
Dissolved oxygen	Not less than 5 mg/liter from April 1 through November 30, and not less than 4 mg/liter at other times.
Temperature	5°F above natural in streams and 3°F above natural in lakes, based on monthly average of the maximum daily temperature except in no case shall it exceed the daily average temperature of 90°F.

Ammonia (N)	1.5 mg/liter.
Chromium (Cr)	0.05 mg/liter.
Copper (Cu)	0.01 mg/liter or not greater than one-tenth the 96-hr TLM value.
Cyanides (CN)	0.02 mg/liter.
Oil	10 mg/liter, and none in such quantities as to (1) produce a visible color film on the surface, (2) impart an oil odor to water or an oil taste to fish and edible invertebrates, (3) coat the banks and bottom of the watercourse or taint any of the associated biota, or (4) become effective toxicants according to the criteria recommended.
pH value	6.5-9.0.
Phenols	0.1 mg/liter and none that could impair odor or taste to fish flesh or other freshwater edible products such as crayfish, clams, prawns, and like creatures. Where it seems probable that a discharge may result in tainting of edible aquatic products, bioassays and taste panels will be required to determine whether tainting is likely or present.
Turbidity value	25.

Fecal coliform organisms	200 most probable number per 100 ml as a geometric mean nor equal or exceed 2,000 most probable number per 100 ml in more than 10% of the samples.
Radioactive materials	Not to exceed the lowest concentrations permitted to be discharged to an uncontrolled environment as prescribed by the appropriate authority having control over their use.

Wastewater Treatment Configurations

Two treatment configurations were evaluated in the load allocation study.

Treatment Configuration No. 1

The WLSSD Treatment Plant will be erected to receive and treat industrial and municipal discharges in the Western Lake Superior Sanitary District. The WLSSD Plant will be located at 27th Avenue West, 2 blocks west of the existing Duluth Main Treatment Plant. The effluent discharge will be parallel to and approximately 1,300 ft from that of the existing Duluth Main Treatment Plant.[9/]

The Superior Sewage Treatment Plant, which is located outside the district boundary, will have secondary treatment facilities.

In this configuration, major point discharges in the study area consist of WLSSD Plant, Superior Treatment Plant, and Superior Fiber Products, Inc.

Treatment Configuration No. 2

With this option, municipalities and industries will treat their wastes independently, except for the Superwood Corporation which will connect its waste flow to the Duluth Main Treatment Plant. All publicly owned treatment works will apply secondary treatment. Industries will apply the Best Practicable Technology (BPT) to the extent necessary to satisfy effluent limits established or in process of being established by EPA and Minnesota PCA.

Loadings at 1977 Effluent Limits

The 1977 effluent limits for industries in the study area were specified in draft NPDES permits supplied to this study by the project officer. Tables 31 through 34 present proposed effluent limits for, respectively, Conwed Corporation, Northwest Paper Company, U.S. Steel Corporation, and Superior Fiber Products. Superwood Corporation has elected to discharge wastes to the public treatment system (i.e., Duluth Main Treatment Plant).

For publicly owned treatment works, except the WLSSD Plant, the 1977 effluent levels are those defined by EPA, and published in Federal Register, 38(159), pp. 22298-22299, 17 August, 1973.

Tables 35 and 36, respectively, summarize discharge data for Treatment Configurations Nos. 1 and 2. In both tables, the present discharge figures are also given for comparison.

Projected Water Quality Profiles

Steady-state water quality profiles resulting from Treatment Configurations Nos. 1 and 2 were projected by employing the St. Louis River Model. Projections were made for both summer low flow (570 cfs measured at Scanlon), at 25°C; and winter low flow (410 cfs), at 0°C under ice cover.

General Considerations

The following factors were incorporated into the dissolved oxygen budget within the St. Louis River Model for water quality projections.

a. Carbonaceous biochemical oxygen demand with first order reaction. The reaction rate constant was established with the following temperature correction

$$K_t = K_{20}\theta^{(t-20)}$$

where K_t = rate at temperature t
K_{20} = rate at 20°C
θ = temperature coefficient
t = temperature, °C

In the model, K_{20} was set at 0.172/day; θ at 1.047 for temperatures in the 15 to ~35°C range, and at 1.1 for the lower end of the temperature scale.

Table 31. PROPOSED EFFLUENT LIMITS FOR CONWED CORPORATION[a/]

Parameter	20-day Average	24-hr Composite	Instantaneous Maximum
BOD_5	850 lb/day	1,275 lb	--
Suspended Solids	1,500 lb/day	3,000 lb	--
Phosphorus	--	1 mg/ℓ	--
Oil and Grease	--	--	10 mg/ℓ
Total Coliform		--	1,000 mpn/100 ml

a/ By 1 January 1976.

Table 32. PROPOSED EFFLUENT LIMITS FOR NORTHWEST PAPER COMPANY

- after 12 November 1973

Parameter	Quantity	Other Limits
BOD	27,200 lb/day	--
Suspended Solids	--	To prevent sludge deposition in the river

- after 1 January 1976

Parameter	Quantity	Other Limits
BOD	4,400 lb/day	11 lb/ton of paper produced from bleached Kraft pulp
Suspended Solids	4,000 lb/day	10 lb/ton of paper produced from bleached Kraft pulp
Settleable Solids	--	$\leq$ 0.1 mg/ℓ
Oil and Grease		10 mg/ℓ

Table 33. PROPOSED EFFLUENT LIMITS FOR U.S. STEEL CORPORATION [a/]

Parameter	Discharge Limitations			
	Load, kg/day (lb/day)		Concentration	
	Daily Avg	Daily Max	Daily Avg	Daily Max
BOD_5	410 (950) Gross	645 (1,426) Gross	20 mg/ℓ Gross	30 mg/ℓ Gross
Suspended Solids	410 (950) Gross	645 (1,426) Gross	20 mg/ℓ Gross	30 mg/ℓ Gross
Ammonia	168 (371) Net	226 (500) Gross	8.0 mg/ℓ Net	10.6 mg/ℓ Gross
Cyanide	--	1.85 (4.05) Gross	--	0.086 mg/ℓ Gross
Iron-Total	--	43 (95) Gross	--	2.0 mg/ℓ
Phenol	0.17 (0.371) Net	0.55 (1.2) Net	0.008 mg/ℓ Net	0.03 mg/ℓ Net
Oil and Grease		215 (475) Gross	--	10 mg/ℓ Gross
Fecal Coliform Bacteria	--	--	200/100 ml	400/100 ml
Temperature °C (°F)	--	--	--	b/

a/ Beginning 1 January 1976.

b/ The discharge water shall not cause the receiving stream maximum temperature at the end of the mixing zone to rise more than 1.67°C (3°F) above natural temperatures or to exceed 32.2°C (90°F). Mixing zone is defined as the area of a circle with 600 ft radius. The 3°F temperature rise is an average value over a 30-day period.

Table 34. PROPOSED EFFLUENT LIMITS FOR SUPERIOR FIBER PRODUCTS, INC.

- until 1 December 1974

Parameter	Loadings kg/day (lb/day) Daily Avg	Daily Max	Other Limitations
Discharge 001			
Suspended Solids	450 (1,000)	900 (2,000)	NA
BOD_5	4,500 (10,000)	9,000 (20,000)	NA
pH	NA	NA	4-9

Discharge 002 - Limitation for duration of permit (6-30-78): "The heated effluent shall at no time raise the natural temperature of the receiving water more than 1.7°C (3°F) at the edge of a mixing zone, the area of which does not exceed that of a semicircle with a radius of 60 meters (200 ft), the center point being located at the center of the discharge structure for Discharge Number 002."

- from 1 December, 1974, and until 30 June, 1977

Parameter	Loadings kg/day (lb/day) Daily Avg	Daily Max	Other Limitations
Discharge 001			
Suspended Solids	340 (750)	680 (1,500)	NA
BOD_5	2,950 (6,500)	5,900 (13,000)	NA
pH	NA	NA	6-9

Discharge 002 - Initial conditions still apply.

Table 34 (Concluded)

- from 30 June, 1977, and until 30 June, 1978

Parameter	Loadings kg/day (lb/day) Daily Avg	Daily Max	Other Limitations
Discharge 001			
Suspended Solids	340 (750)	680 (1,500)	NA
BOD_5	635 (1,400)	1,270 (2,800)	NA
pH	NA	NA	6-9

Discharge 002 - Initial conditions still apply.

Table 35. DISCHARGE DATA FOR TREATMENT CONFIGURATION NO. 1

Parameter		WLSSD[a/] Plant	Superior	Superior Fiber Products
Flow, MGD		38.4 (0)	3.67 (3.67)	0.66 (0.66)
BOD_5	mg/ℓ	15 (0)	25 (90)	254 (4,500)
	lb/day	4,811 (0)	766 (2,758)	1,400 (24,800)
Kjeldahl Nitrogen	mg/ℓ	5 (0)	20 (20)	2.81 (2.81)
	lb/day	1,603 (0)	612 (612)	15.5 (15.5)
Ammonia Nitrogen	mg/ℓ	1 (0)	28 (28)	1.4 (1.4)
	lb/day	320 (0)	858 (858)	7.7 (7.7)
Nitrite Nitrogen	mg/ℓ	0.1 (0)	0.1 (0.1)	0.47 (0.47)
	lb/day	32 (0)	3.07 (3.07)	2.6 (2.6)

a/ Data obtained from Mr. Don Stulc, WLSSD, 22 April, 1974.

Note: Data in parentheses are present discharge figures.

Table 36. DISCHARGE DATA FOR TREATMENT CONFIGURATION NO. 2, 1977 GUIDELINES[a/]

		CONWED Corporation	Northwest Paper Company	U.S. Steel Corporation	Superior Fiber Products	City of Cloquet	Scanlon Village	Gary-New Duluth Treatment Plant	Superior Treatment Plant	Smithville Treatment Plant	Fairmont Treatment Plant	Duluth Main[b/] Treatment Plant
Flow	mgd	1.3836 (1.3836)	27.1 (27.1)	15.60 (15.60)	0.66 (0.66)	1.4886 (1.4886)	0.13 (0.13)	0.21 (0.21)	3.67 (3.67)	0.320 (0.320)	0.68 (0.68)	18.85 (18.25)
BOD_5	mg/liter	73.5 (1,050)	19.4 (400)	7.3 (51.7)	254 (4,500)	25 (100)	25 (125)	25 (50)	25 (90)	25 (50)	25 (49)	25 (76)
	lb/day	850 (12,134)	4,400 (90,564)	950 (6,736)	1,400 (24,800)	310 (1,243)	27 (136)	44 (88)	766 (2,758)	67 (133)	142 (278)	3,936 (11,566)
Kjeldahl Nitrogen	mg/liter	6.5 (6.5)	5.2 (5.2)	3.0 (55)	2.81 (2.81)	22.5 (22.5)	20 (20)	20 (20)	20 (20)	20 (20)	20 (20)	17.1 (17.1)
	lb/day	75 (75)	1,177 (1,177)	385 (7,166)	15.5 (15.5)	279 (279)	22 (22)	35 (35)	612 (612)	53 (53)	113 (113)	2,692 (2,607)
Ammonia Nitrogen	mg/liter	2.4 (2.4)	0.9 (0.9)	2.8 (53)	1.4 (1.4)	28 (28)	28 (28)	28 (28)	28 (28)	28 (28)	28 (28)	28 (28)
	lb/day	28 (28)	204 (204)	371 (6,905)	7.7 (7.7)	384 (384)	30 (30)	49 (49)	858 (858)	74 (74)	159 (159)	4,409 (4,268)
Nitrite Nitrogen	mg/liter	3.5 (3.5)	1.6 (1.6)	0.1 (0.1)	0.47 (0.47)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)
	lb/day	40 (40)	362 (362)	13 (13)	2.6 (2.6)	1.24 (1.24)	0.1 (0.1)	0.18 (0.18)	3.1 (3.1)	0.27 (0.27)	0.57 (0.57)	15.7 (15.2)

a/ Data in parentheses are present discharge figures.
b/ Receiving discharges from Superwood Corporation.

b. Ammonia oxidation with first order reaction rate constant of 0.02/day at 25°C and 0.0023 at 0°C.

c. Nitrite oxidation with first order reaction rate constant of 0.03/day at 25°C and 0.0033 at 0°C.

d. Algal oxygen respiration and production rate as function of water temperature.[10]

$$< P\text{-}R > = \frac{\alpha - \pi}{\pi\ (\alpha - 1)}\ [25 - 0.025\ (t - 30)^2]\ mg/\ell/day$$

where $\alpha = 3.190$
$\pi = 3.1416$

e. Reaeration from atmosphere as a function of oxygen deficiency with rate constant as function of temperature, depth, H (ft), and velocity U (ft/sec).[11]

$$K_a\ (1/day) = (K_a)_{20}\ \theta^{(t-20)}\ \frac{U^{1/2}}{H^{3/2}}$$

where $\theta = 1.024$
$(K_a)_{20}$ = 12.9 for the bay area and 10.6 for the river from Brookston to the Oliver Bridge.

f. Reaeration at dam sites as function of temperature and fall height, h (ft).[12]

$$r = 1 + 0.11\ ab(1 + 0.046\ t)h$$

where r = deficit ratio, defined as $\frac{C_s - C_A}{C_s - C_B}$

C_s = DO at saturation
C_A = DO above the fall
C_B = DO below the fall
h = fall in feet
a,b = constants
a = 1.25 if BOD is less than 5
a = 1.0 if BOD is greater than 5 and less than 15
a = 0.8 if BOD is greater than 15
b = 1.0

g. Solubility of oxygen in water as function of temperature.[13]

$$C_s = 14.652 - 0.41022t + 0.0079910t^2 - 0.000077774t^3$$

h. Benthic oxygen demand rates taken as zero for winter; 6.7 $g/m^2/day$ in the summer for Fond du Lac Lake and Scanlon Reservoir; and 6.05 $g/m^2/day$ for Forbay Lake, Thomson Reservoir, and pools above the Northwest Paper Company Dam and Knife Falls Dam, for the summer period. A complete coverage of sludge on reservoir bottoms is assumed in the model. These benthic uptake rates are within the range of measurement conducted in this program, and consistent with demands reported elsewhere for cellulosic fiber sludge.[11] This range is approximately twice that reported for St. Louis River Basin bottom sludge in 1966.[14]

i. Dispersion coefficient as function of channel velocity, head differences at ends of channel, and hydraulic radius.[15]

$$D_d = C \cdot E^{1/3} \cdot \ell^{4/3}$$

where $C = 0.0136$ (empirical constant, dimensionless)

$$E = U_i \cdot g \frac{\Delta H}{L_i}$$

U_i = channel velocity
g = gravitational constant
ΔH = potential (head) difference at ends of channel
L_i = channel length
ℓ = scale of phenomenon; written in terms of the hydraulic radius, R.

Computation Results

The results of DO projections for both treatment configurations at summer low flow are shown in Figures 10 and 11. Also shown in these figures are stream standard DO values, and DO at saturation at the respective temperature and period of the year.

It is seen that, at summer low flow, with the 1977 effluent limits, the projected DO profiles resulting from both treatment configurations will violate the proposed water quality standard. The critical zone is the 10-mile river stretch from Fond du Lac Bridge to Thomson Lake. The lowest predicted DO is $\cong$ 1 ppm, occurring at Fond du Lac Dam and Upper Gate.

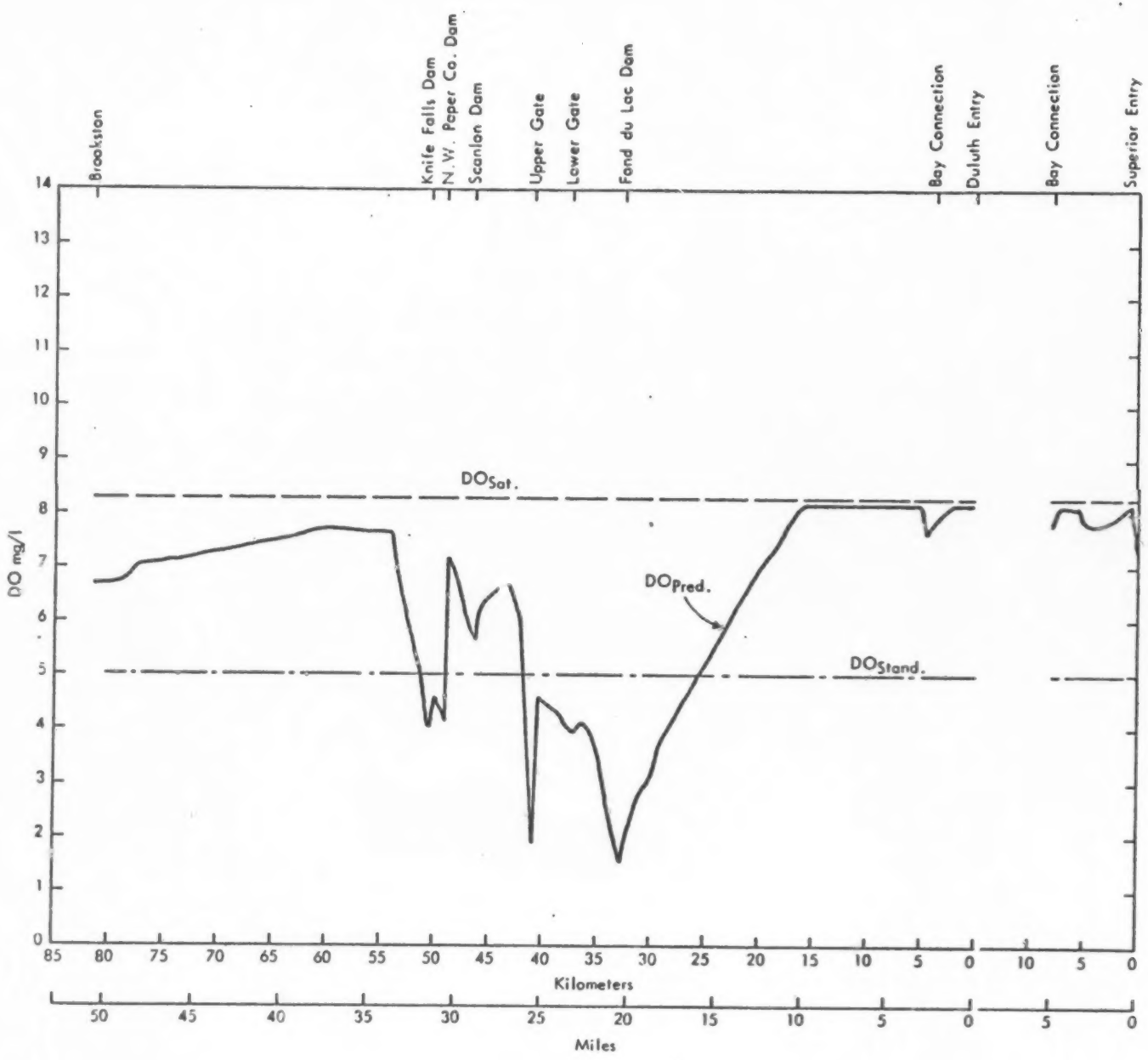

Figure 10. Projected DO Level for 7-Day 10-Year Summer Low Flow With No. 1 Treatment Configuration at 1977 Effluent Limits

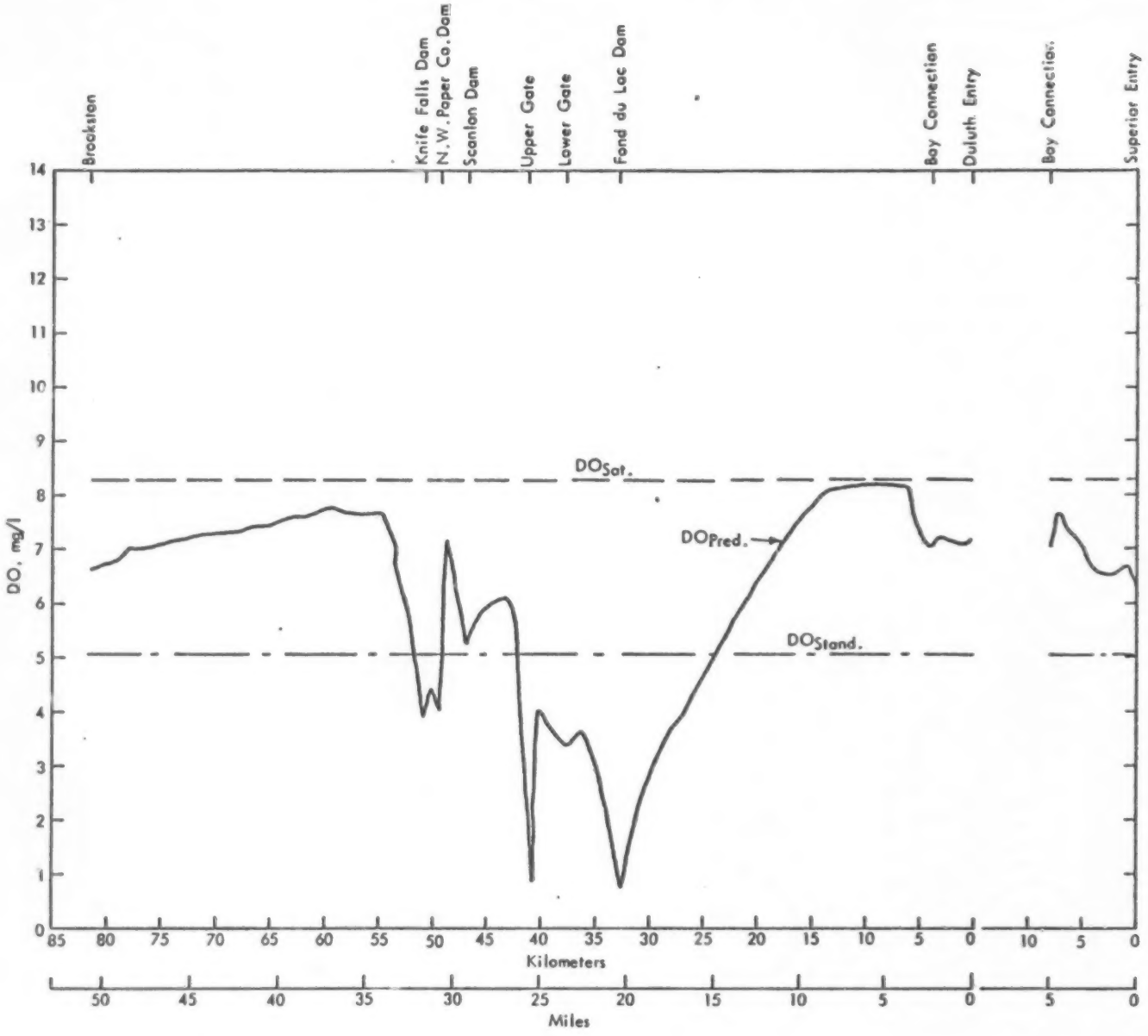

Figure 11. Predicted DO Levels for 7-Day 10-Year Summer Low Flow with No. 2 Treatment Configuration at 1977 Effluent Limits

In the bay areas, DO will not be a problem for either of the two treatment configurations.

It is apparent from the location of DO sag, and from variations in CBOD and NBOD in the river that the most important factor dominating DO in the area is the oxygen demand of bottom sludges in reservoirs. To verify this point, three computer runs were made, with the specific input conditions: (1) zero discharge from point sources, with current benthic uptake rates; (2) half of the current benthic uptake rates, and 1977 effluent limits for No. 2 configuration, and (3) half of the current benthic uptake rates, with assumed zero discharge from municipal and industrial sources. The results, as shown, respectively, in Figures 12, 13, and 14, indicate that, even if all point discharges are reduced to zero, the DO level will improve only slightly if benthic demand remains as at present (see Figure 12). However, if benthic uptake rates are assumed to be 50% of the rates measured in 1973, DO levels will be close to the proposed standard with No. 2 treatment configuration (at 1977 effluent limits) (see Figure 13), and will satisfy standards with zero discharge from point sources (see Figure 14).

The projected DO levels for winter low flow, at 410 cfs, 0°C temperature, with ice cover except at dam sites, are given in Figures 15 and 16, for Treatment Configurations Nos. 1 and 2, respectively. Except for part of Superior Bay with No. 2 configuration (see Figure 16), DO will not be a problem for the entire stretch of river. The possible violation of DO in the bay area is due to the greater total point source loading in No. 2 configuration than in No. 1 configuration. Projected water quality for the winter low flow condition is based on the assumption that no back-mixing of Lake Superior water occurs to dilute pollutants in the bay areas. Since the ice cover will substantially eliminate the seiche effect, little backmixing during the winter months is expected and projected quality in the bay areas is accordingly expected to be close to actual quality under future winter conditions.

In general, DO levels are more favorable in winter, despite ice cover, than in summer. This can be attributed to (1) higher DO levels in water coming into the system, (2) lower CBOD and NBOD oxidation rates, and (3) assumed zero benthic uptake rate, during winter months.

For Treatment Configuration No. 2, as seen in Table 36, Conwed Corporation and Superior Fiber Products are allowed to discharge BOD_5 at 73.5 and 254 mg/liter, respectively. A computer run was made to examine the effect of adjusting these two discharge figures to 25 mg/liter, equivalent to municipal discharges. The results are shown in Figure 17. Only a slight improvement is achieved. This can be attributed to the relatively small loading from these two sources as compared to the total amount of pollutants existing in the entire river system.

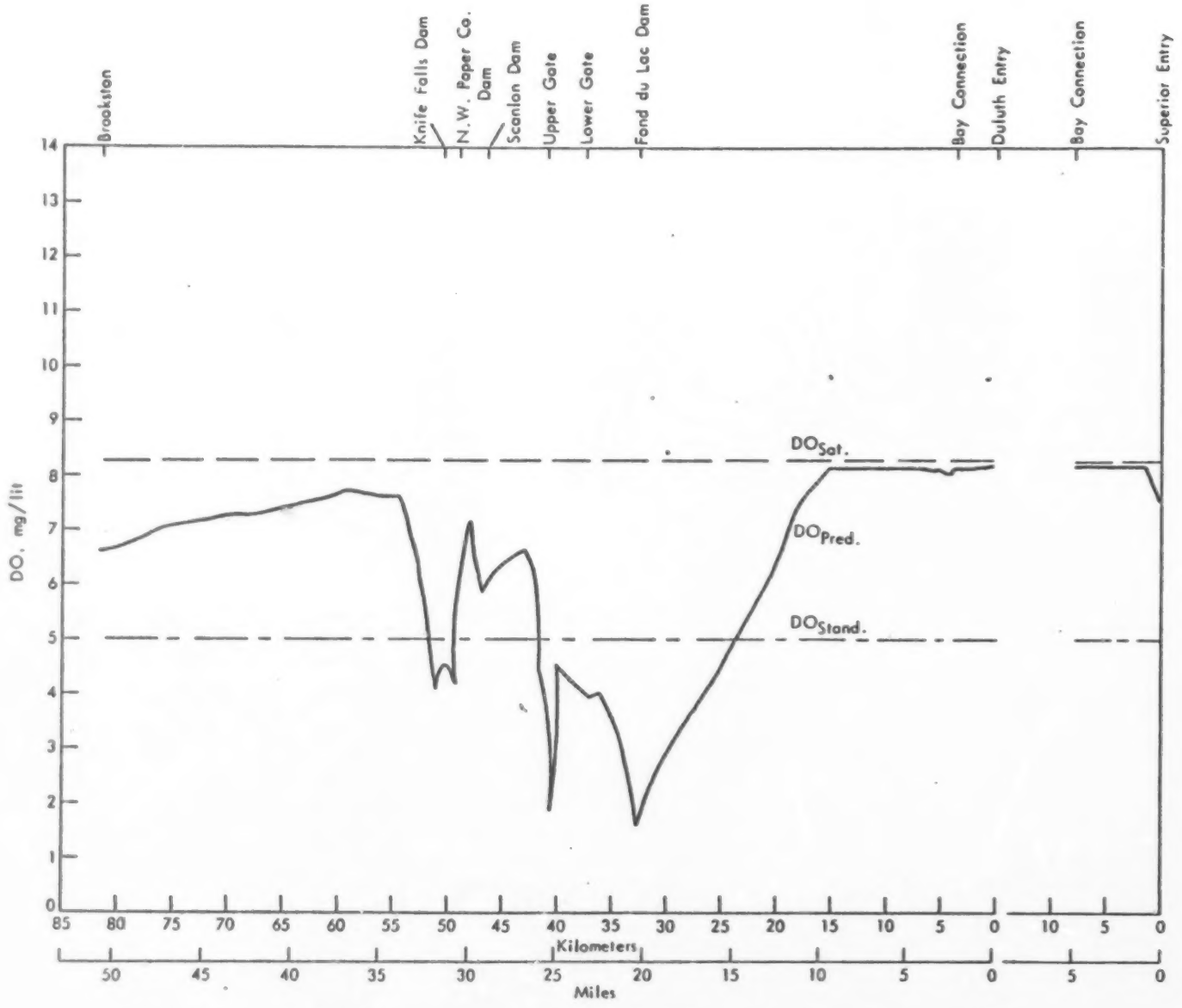

Figure 12. Projected DO Level for 7-Day 10-Year Summer Low Flow With Assumed Zero Discharge from Point Sources

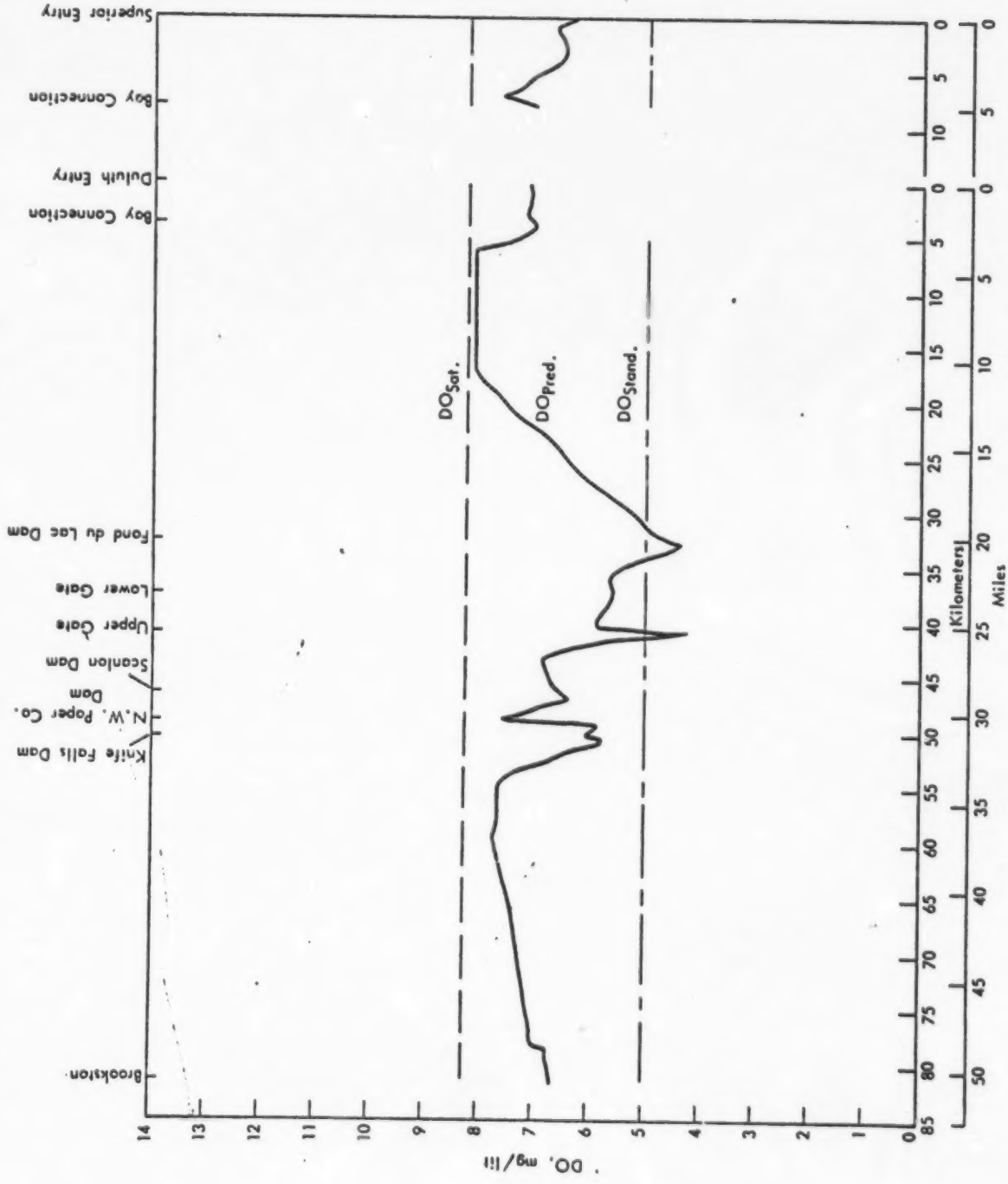

Figure 13. Projected DO Level for 7-Day 10-Year Summer Low Flow with No. 2 Treatment Configuration at 1977 Effluent Limits, and with 50% of Benthic Uptake Rates Measured in 1973

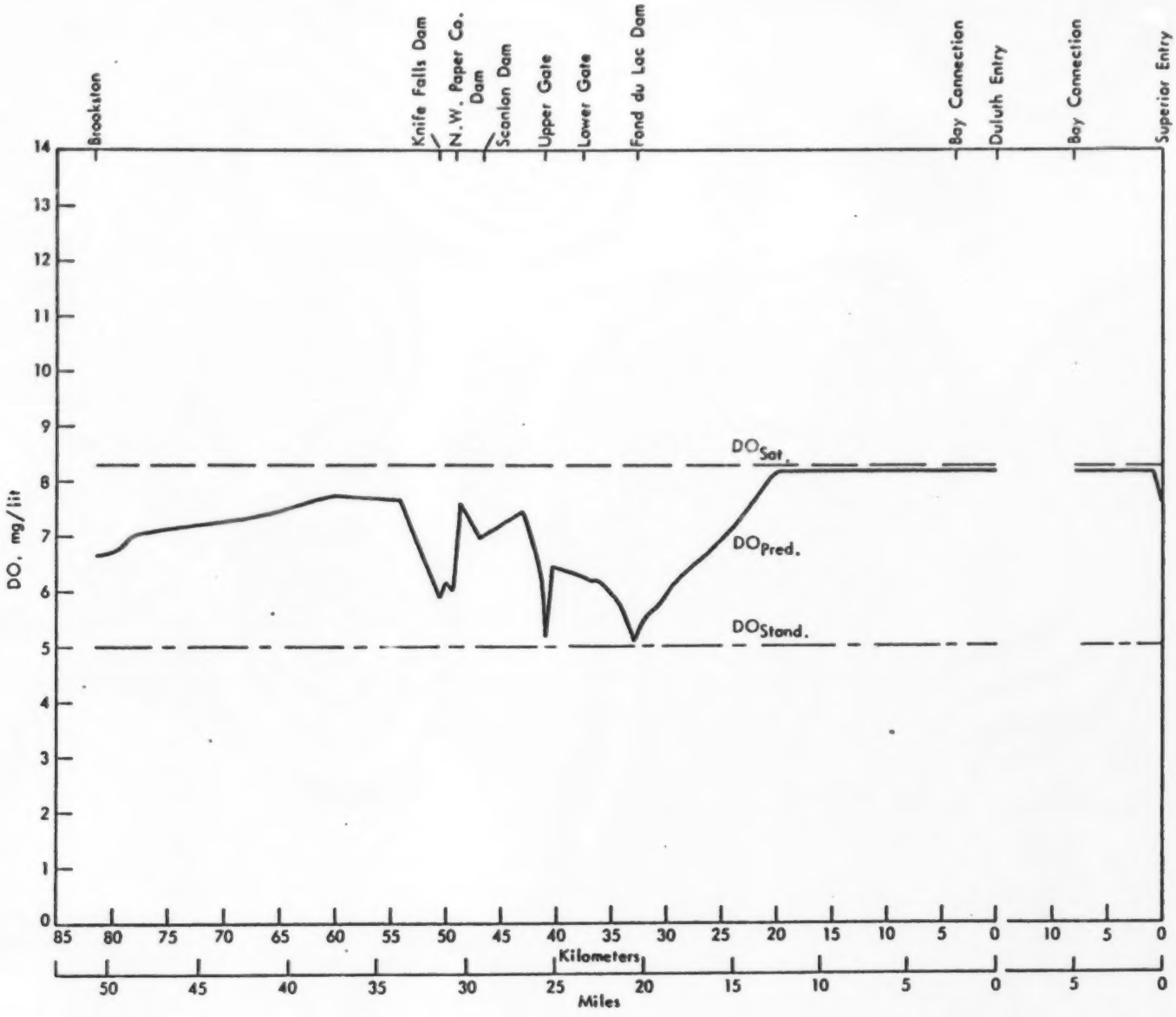

Figure 14. Projected DO Level for 7-Day 10-Year Summer Low Flow With Assumed Zero Discharge from Point Sources, and 50% of Benthic Uptake Rates Measured in 1973

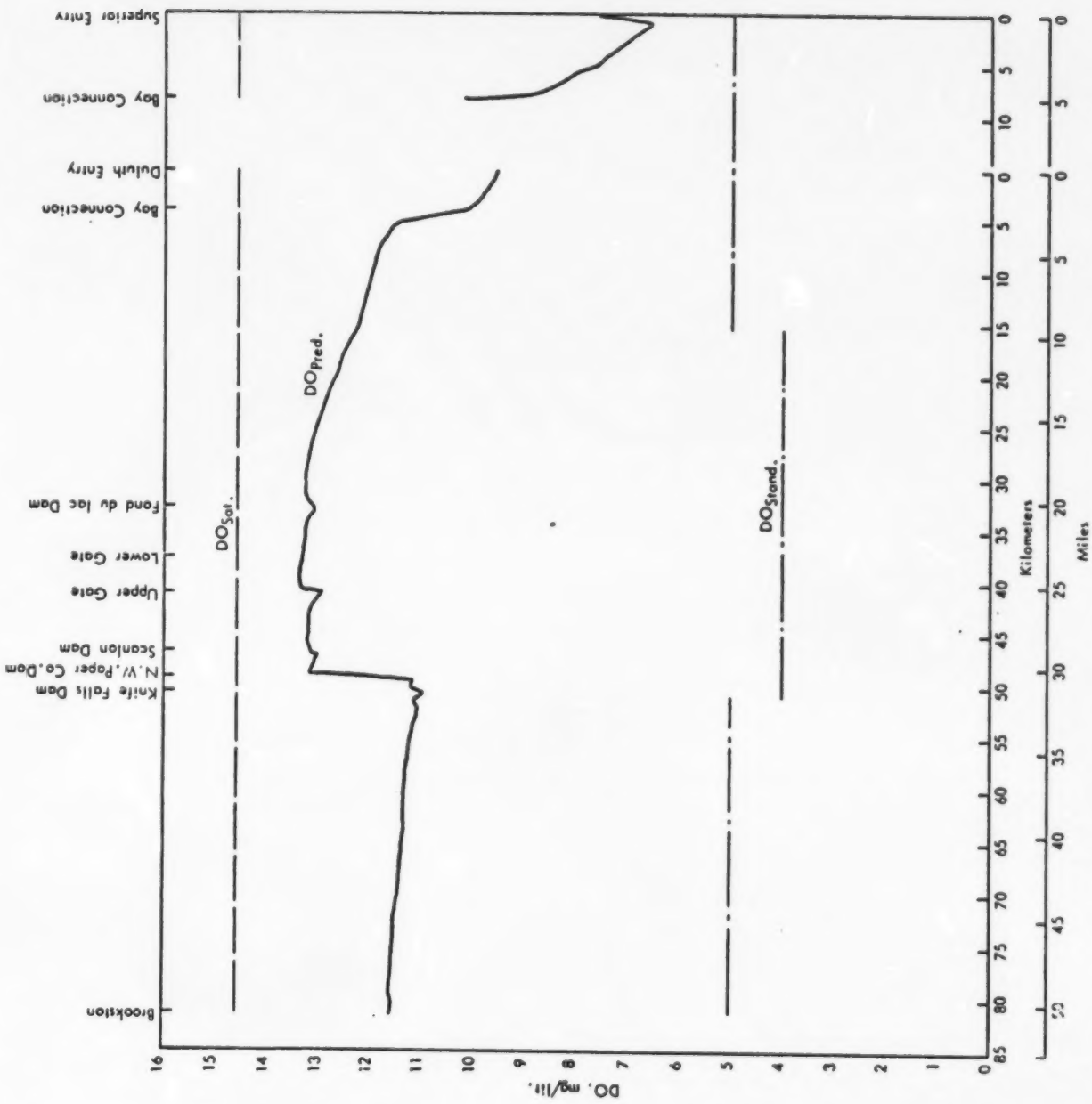

Figure 15. Projected DO Level for 7-Day 10-Year Winter Low Flow Under Ice Cover, with No. 1 Treatment Configuration at 1977 Effluent Limits

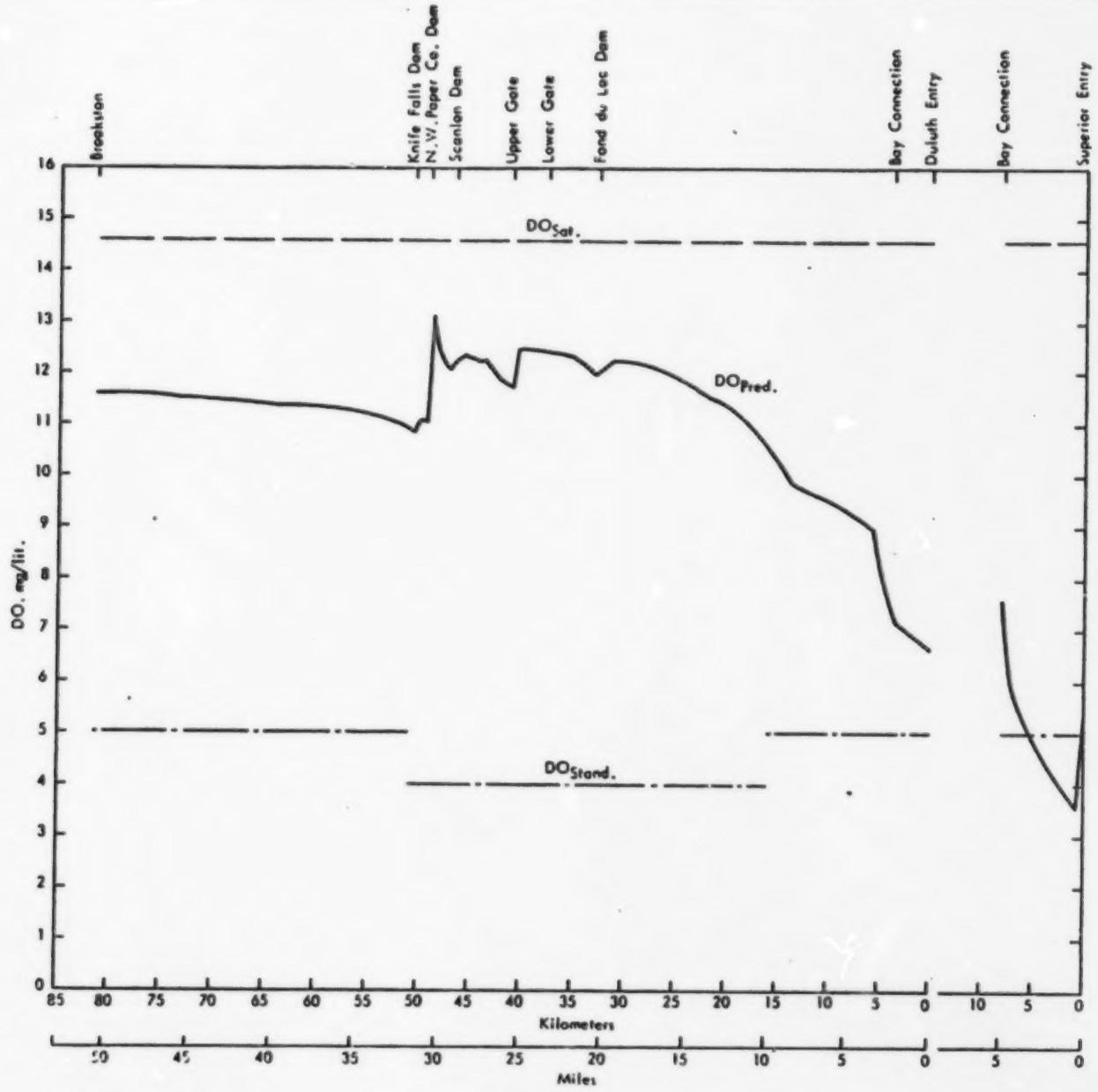

Figure 16. Projected DO Level for 7-Day 10-Year Winter Low Flow Under Ice Cover, with No. 2 Treatment Configuration at 1977 Effluent Limits

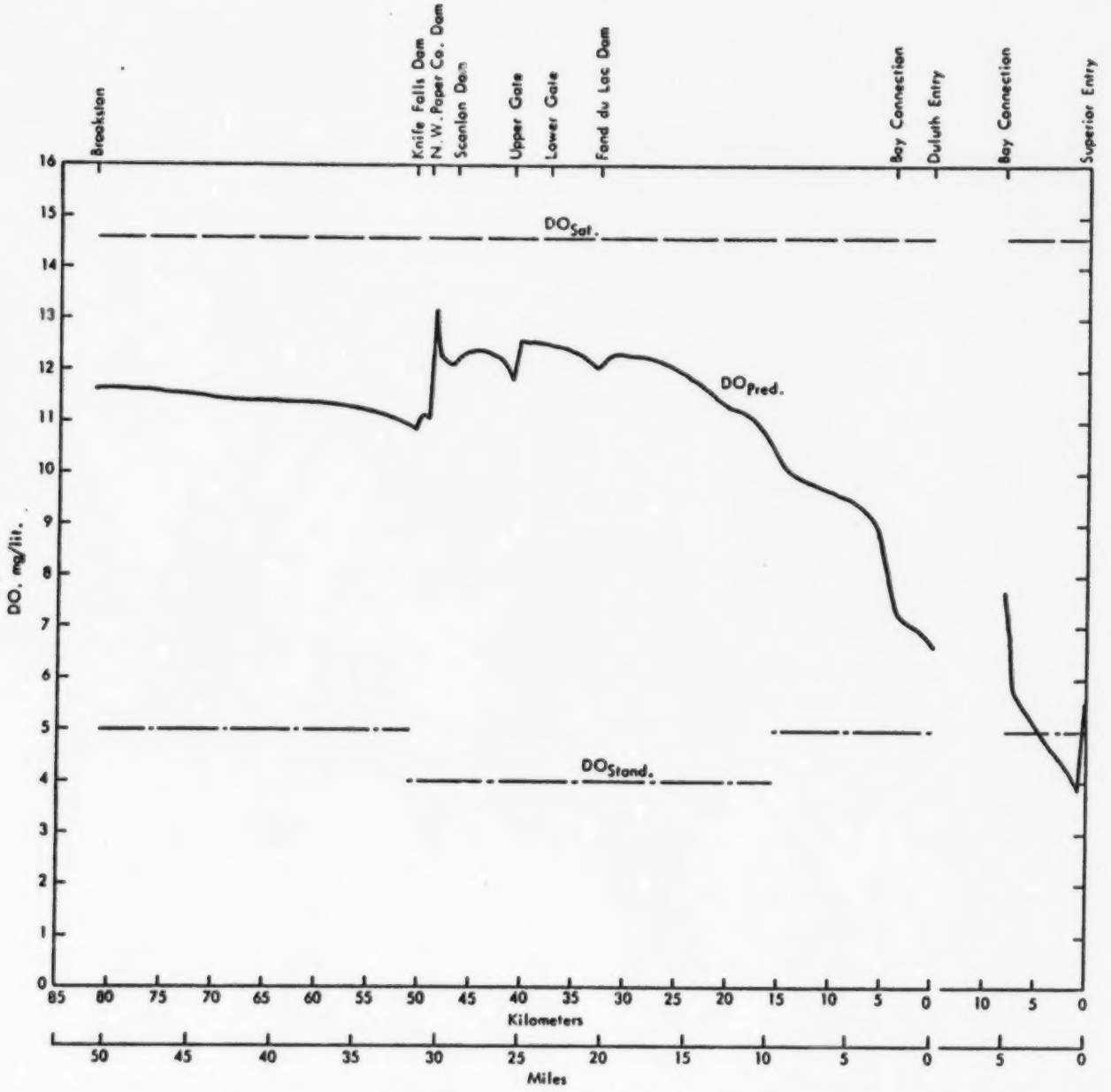

Figure 17. Predicted DO Level for 7-Day 10-Year Winter Low Flow with Ice Cover, and No. 2 Treatment Configuration. All point source discharges are at 1977 effluent limits, except Conwed and Superior Fiber reducing BOD concentration to 25 mg/ℓ.

SECTION VI

DISCUSSION

SOURCE FACTORS AFFECTING WATER QUALITY LEVELS

Water quality levels in the St. Louis River are affected by discharges from various sources: natural sources, municipal and industrial sources, and shipping wastes. These sources contribute varying proportions of the total loadings to the river for different types of pollutants. Industrial discharges, for example, currently account for 78% and 53% of total loadings of BOD and suspended solids, respectively. On the other hand, natural sources contribute about 70% of dissolved solids in the river.

For dissolved oxygen, this study has found that the benthic demands of bottom sludges in the reservoirs is a critical or limiting parameter. The bottom sludges are therefore properly viewed as pollutant sources, sources which water quality planners must include in assessment of options for improvement of water quality.

Table 37 delineates contributions of water, BOD, total nitrogen, total dissolved solids, suspended solids, and coliforms to the St. Louis River. Calculations were based on summer discharge conditions, at a typical flow of 1,500 cfs (measured at Scanlon). Natural sources include the mainstream input at Brookston, and inputs from 23 tributaries.

WATER QUALITY AT SUMMER LOW FLOW

Stream standards are presently violated over most of the basin under summer conditions, including flows some three times the 7-day, 10-year summer low flow condition of 570 cfs. Water quality improves markedly with all discharges located as at present but improved to conform to 1977 effluent guidelines. The principal exception--and a substantial one--is the quality of water in the reservoirs. It is apparent

Table 37. SUMMARY OF POLLUTANT DISCHARGES IN 1973 TO THE ST. LOUIS RIVER (MINNESOTA, WISCONSIN)[a/]

	Natural	Municipal	Industrial	Shipping	Total
BOD					
lb/day	25,092	16,168	150,263	1,895	193,418
%	12.9	8.4	77.7	1.0	
Total Nitrogen					
lb/day	11,648	9,983	16,506	5,247	43,384
%	26.9	23.0	38.0	12.1	
Total Dissolved Solids, lb/day	1,194,741	67,531	303,255	123,787	1,689,314
%	70.7	4.0	18.0	7.3	
Suspended Solids					
lb/day	56,317	12,149	80,780	4,671	153,917
%	36.6	7.9	52.5	3.0	
Coliforms					
MPN/100 mℓ	≅ 15,000	30 ~ 8,000	2,000 ~ 100,000,000	900,000 ~ 1,300,000	
Flow					
cfs	1,590	38.7	70.9	28.9	1,728.5
MGD	1,016	24.7	45.3	18.4	1,104.4
%	92.0	2.2	4.1	1.7	

a/ Summer conditions at a typical flow of 1,500 cfs at Scanlon.

that benthic sludge activity limits the quality which can be achieved in this midsection of the basin. DO levels in the reservoirs are depressed below the stream standard (5 ppm DO) when industrial and municipal effluents, at the 1977 level, are discharged to the river basin (see Figure 11). Figures 12 and 14 depict water quality with zero discharge and with benthic activity (oxygen demand) at two levels (current measured oxygen demand and 50% of current demand): with the current measured benthic oxygen demand, DO dips below 5 ppm in the reservoirs, and satisfactory DO ($\geq$ 5 ppm) levels are barely achieved when the lower benthic oxygen demands are assumed.

The modeling and projection results clearly indicate that compliance with 1977 guidelines would provide conformance with current stream standards, if benthic sludges accumulated over many years were not present in the reservoirs. Current stream standards for DO cannot, however, be met in the reservoirs with no discharges above the WLSSD treatment plant discharge, which provides (in effect) compliance with 1983 guidelines for the mid to upper sections of the basin.

The benthic sludges will decrease in activity with time, barring repeated disturbance of sludge beds (by flood waters, for example). How quickly the recovery process will occur is not known. One concludes, however, that recovery will be quickest with Treatment/Discharge Configuration No. 1, in which all upstream point discharges are collected and treated by WLSSD.

WATER QUALITY UNDER WINTER CONDITIONS

Biological processes are quite slow under winter conditions, essentially 0°C, and with ice cover the river functions much as a pipeline in which reaeration occurs only periodically, at the dams/power stations. In the upper stretches of the basin, DO levels are high, a gradual decrease is observed as one moves downstream, and reaeration at the dams helps to replenish the slowly diminishing supply of oxygen. At the 7-day, 10-year winter low flow of 410 cfs, dissolved oxygen in the lower sections of the Bay area dips slightly below the 5 ppm stream standard with Treatment Configuration No. 2 (1977 guidelines, discharges located as at present). DO in the Bay area decreases very slowly, however, and about 100 days is required to reach a steady state DO level below the stream standards. No violation will occur with the No. 1 Configuration.

One concludes, therefore, that wintertime water quality will be better than stream standards at the 1983 condition, and will violate

standards with 1977 effluent standards only if extremely low flows persist throughout the winter ice covered period.

RELATION OF "STEADY STATE QUALITY" TO QUALITY IN A DYNAMIC SYSTEM

Flowing streams usually remain at one condition for a relatively short period of time, as flows change in response to rainfall, temperature change with seasons, etc. A low flow condition may, for example, persist for as short a time as a few days, or as long as a few weeks.

Calculations with the St. Louis River model indicate that equilibria (steady state) are achieved, depending on location, and flow and discharge conditions, after 10 days to more than 3 months. Progress toward steady state is 80-90% complete in perhaps 4-20 days, however. The user of the model should keep this fact in mind: calculated, steady state water quality conditions will likely be slightly higher (or lower) than observed conditions, because the model tends to overshoot the condition which exists in a dynamic river system. The following example illustrates this point.

Water quality for the summer flow condition, 2,400 cfs, was calculated from an initial condition of 1,500 cfs, and levels of water quality (DO, etc.), which existed at steady state at that condition. After 8 days, DO had increased from 2.0 ppm to 3.8 ppm at the Oliver Bridge (river kilometer point = 23), and the steady state level of 3.9 ppm was reached after 12 days. This model simulation also indicated that, at a flow of 2,400 cfs, 32 days are required before the steady state DO levels are reached in the Superior Bay area. The calculated steady state value is thus the value which will result only if flow persists at 2,400 cfs for quite a long period of time. Actual water quality parameter values will be usually transitional values rather than steady state values. In periods of rapid change, in flow or in temperature for example, stream water quality may differ substantially from calculated water quality at steady state. The difference between actual and steady state values will usually not be great, but future users of the model should keep this factor in mind.

THE SEICHE PHENOMENON IN RELATION TO WATER QUALITY AND THE ST. LOUIS RIVER MODEL

The St. Louis River model is judged to be an excellent model, with one exception which does not materially decrease its usefulness.

The downstream segment of the St. Louis River Basin is affected by the irregular, tidal-like seiche effect, a reverse flow phenomenon

which occurs about 200 times per year. The seiche phenomenon is believed to be responsible for the only significant shortcoming of the model. In the absence of data on mixing, dispersion, and reverse flows in the Bay area, it was assumed that flows were linear and that no mixing or dispersion from the seiche effect occurred. Low DO values were accordingly calculated in the Bay area, particularly toward the Superior Entry to Lake Superior. Low DO values are contrary to general local experience, although firm data on DO in Superior Bay were not available as of early 1974 (WLSSD has since measured DO in the Bay and found it to be in excess of 5 mg/liter).

It must therefore be concluded that the St. Louis River model as presently constructed does not accurately describe hydrology and water quality in the Bay area during time periods when the seiche phenomenon occurs (spring, summer, and fall). In the winter, when the streams and Bay areas are ice covered, reverse flows should be minimal and the water quality parameters calculated with the model should be accurate; this conclusion has not been verified, however. Recification of this failing was beyond the scope of the present program, and basic data on hydrology and water quality needed to make and verify necessary modifications are not available.

QUALIFICATIONS BASED ON OTHER SPATIAL/FLOW FACTORS

The water quality profiles, current and projected, presented in this report are correct with no known exceptions for all parts of the system from Brookston through the reservoirs, as are conclusions and observations drawn for this upper part of the basin. The profiles of water quality in the Bay areas developed and presented in this report apply primarily to the shipping channels, and care must be exercised in generalizing conclusions to off-channel parts of the lower basin. A case in point is the area into which the pending WLSSD treatment plant effluent is scheduled to be discharged. The region of discharge is relatively shallow, and flows are sluggish. As a consequence, the localized area will function (according to results calculated by the model) essentially as a holding pond for the WLSSD discharge, and stream standards will be violated within this relatively small region. The same type of effect can be expected in other hydrologically isolated pockets in the Bay area, though violation of stream standards is expected to be only a rare possibility.

SECTION VII

RECOMMENDATIONS

Three recommendations are presented. The first involves further elucidation of the water quality in the Bay areas, as it is affected by backmixing from Lake Superior. The second recommendation deals with benthic activity in the reservoirs. The third is concerned generally with upgrading the data base and the St. Louis River model, through systematic monitoring and accumulation of data on the basin.

BACKMIXING IN RELATION TO WATER QUALITY

The St. Louis River model has one limitation which should be rectified, preferably while discharges and water quality are the same or similar to conditions existing at the time of model verification. The limitation stems from the fact that the Bay areas are much more complex hydraulic systems than has been assumed in the model, and calculated water quality is inferior to accepted though poorly documented water quality in the Bay areas. Backmixing which accompanies the seiche effects is not presently included in the hydraulic model, and calculated water quality is thus poorer than actual water quality.

The seiche is an irregular phenomenon, and thus its effect on hydraulics and water quality will be more difficult to model than are regular tidal flows.

It is conceivable that water quality in the Bay areas, especially Superior Bay, approaches that expected if essentially complete mixing of lake and bay waters occur. If such proves to be the case, modification of the St. Louis River Model can be effected fairly simply. If, as is more likely to be the case, the degree of backmixing varies irregularly over a broad range, water quality will be sensitive to the seiche and tend to violate stream standards when backmixing is limited. Such a situation will be more difficult to model.

Before initiating additional model development aimed at correcting this defect, two steps are recommended. First, stations in the Bay areas should be monitored for water quality for several months, particularly during the warm weather seasons. The results will show how water quality varies in response to the seiche, and whether quality does or does not violate stream standards. Second, records on the seiche should be examined with the objective of determining whether its amplitude and frequency are regular enough to permit development of a relatively simple model. These two activities will provide the means to assess the need for model modification, and to assess as well the difficulty of effecting the modification.

The St. Louis River Model is a modified Columbia River Model, which has the capability to model tidal basins. Model modification should, therefore, be based on the present St. Louis River Model.

PROJECTION OF BENTHIC DEMANDS

Recovery of water quality in the reservoirs, in response to point discharge control, will be a function of the rate of dissipation of benthic sludges. This problem needs to be analyzed to determine, if possible, how quickly (or slowly), the bottom sludges will become deactivated, so that the water quality in the reservoirs can be projected with confidence after sludge/solid discharges eliminated. The analysis should include in situ measurement of benthic demands to substantiate or modify present data; examination of research results and field experience elsewhere on rates of decrease of benthic oxygen requirements; and assessments of rates of sediment deposition in the reservoirs in order to develop the basis to determine whether bottom sludges will become covered with mineral sediments and thus effectively be deactivated. At the same time, estimates should be made of the probability that sludge deposits will be disturbed and reactivated by flood, bottom fish, thermal turnover, etc. The information assembled in these activities should then be collectively analyzed in order to develop a projection of sludge activity in the future.

DATA AND MODEL UPGRADING

It is recommended that water in the basin, particularly below the reservoirs, be systematically monitored. Possible trouble spots--coves, off-shipping-channel dead spots, locations in close proximity to current or proposed discharges, etc., should be checked.

In addition, more detailed information is needed for certain aspects of hydrology, water quality, river geometry, and effluent discharges for the Lower St. Louis River Basin. Monitoring and data collection should be continued with three objectives: (1) to develop a total data base which adequately describes conditions in the basin which affect water quality; (2) to identify potential water quality problems and solve them in the planning process; and (3) to upgrade the capabilities and sensitivity of the St. Louis River Model.

Data deficiencies and information needs are presented briefly below:

1. Information on discharges from municipalities and industries, particularly data which describe quality characteristics, is not sufficient. Data deficiencies include parameters such as nitrogen, phosphorus, coliforms, sulfides for municipal discharges, and sulfides and coliforms for industrial discharges.

2. Data on shipping wastes, including sanitary waste, bilge water and ballast water, are insufficient and lack the detail needed to quantify waste loadings from shipping activities in the harbor area.

3. Very little data are available on quality and quantity aspects of tributaries, particularly large and/or polluted tributaries. These tributaries include: Cloquet River, Stoney Brook, Midway River, Crystal Creek, Silver Creek, Pokegama River, Nemadji River, and Bluff Creek.

4. Pollutants from nonpoint sources, including those carried in rural runoff and those from swamps and peat bogs, also contribute to pollution of water in the area. Current available information is far from sufficient to characterize loading from these sources.

5. Additional sampling stations are needed, particularly in the Duluth-Superior-Bay regions, and more complete analysis of water quality is needed for the various forms of phosphorus and nitrogen, and for plant life and indicators of plant life.

6. Data which characterize the geometry of the river from the Oliver Bridge to Brookston are considered to be inadequate.

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